Grid Integration of Variable Renewable Energy

Positive and negative balancing power needs for system operation and planning

Albrecht Tiedemann

renac
renewables academy

www.renac.de

Agenda

renac
renewables academy

1. Disturbed balance between generation and consumption
2. Types of reserves and balancing power calculation
3. Balancing power calculation with probabilistic approach and common distribution function of imbalances
   - Power plant outage distribution
   - Load forecast error distribution
4. Balancing power calculation with probabilistic approach - exercises with excel tool
5. Dynamic balancing power calculation example

AGENDA

Learning objectives

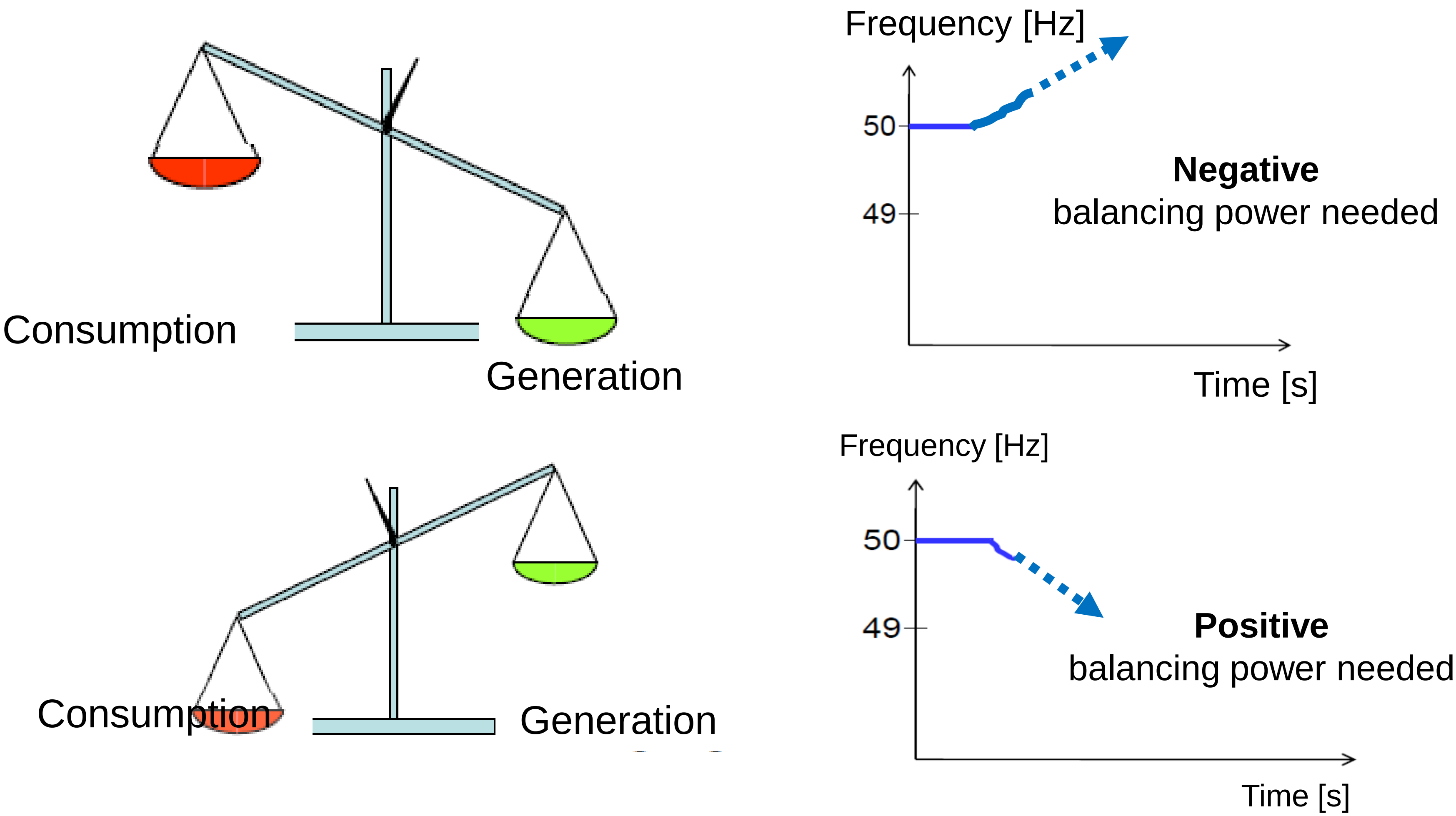
renac renewables academy

- A participant who has met the objectives of the course will be able to
  - name reasons for power imbalances and balancing power needs
  - define types of reserves and balancing power requirements
  - combine different distribution functions of imbalances to dimension balancing power needs
  - use a probabilistic balancing power calculation tool to calculate the amount of positive and negative balancing power needed to ensure a certain system reliability

1 Positive and negative reserves to manage disturbed balance between power generation and consumption

Disturbed balance between generation and consumption and positive/negative balancing power needs

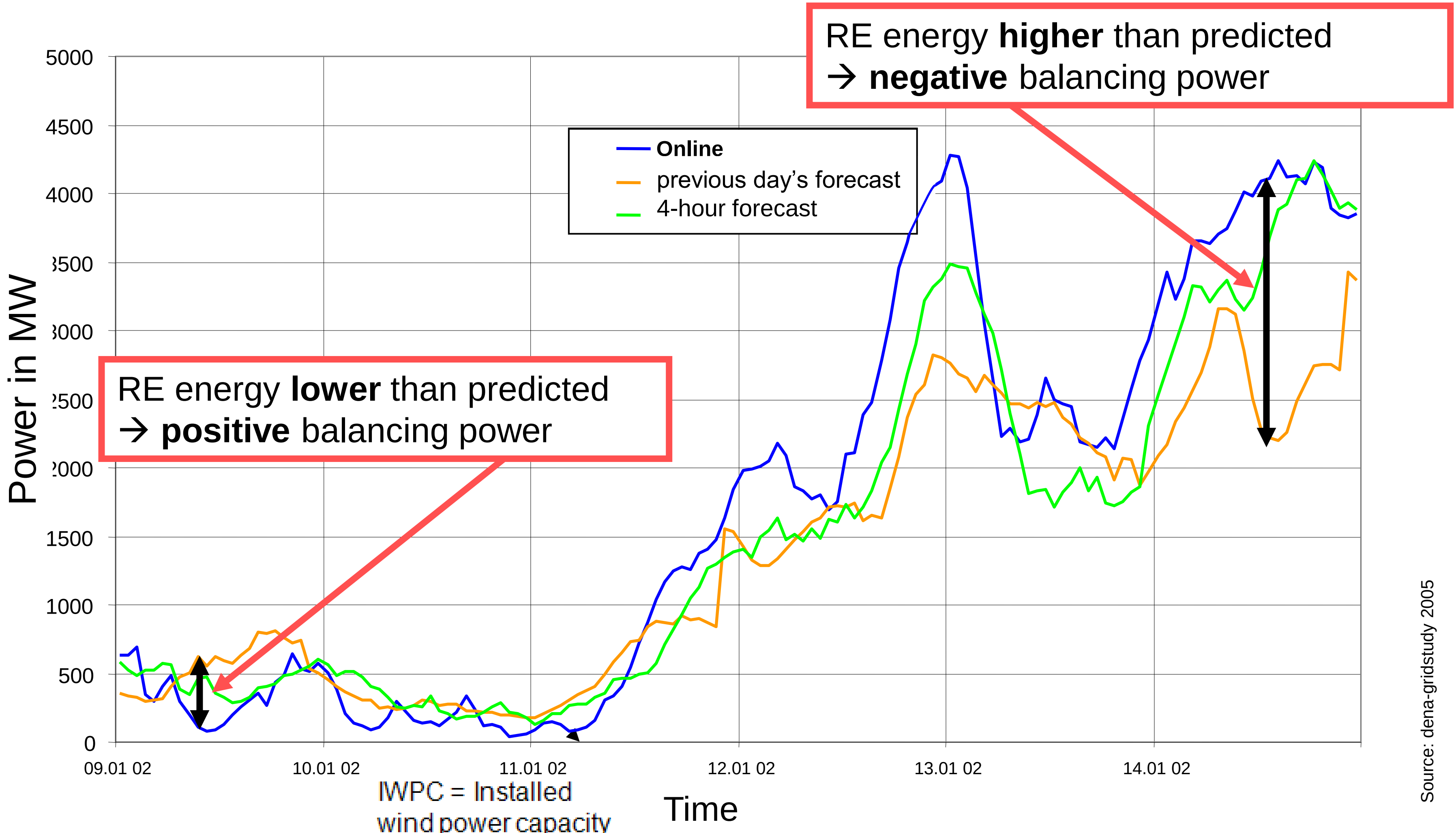
renac
renewables academy



Reasons for power imbalances and balancing power needs

- Power generation:
  - Unexpected blackout of power stations
  - Deviation of power stations from schedules
  - Short term forecast errors of wind power and solar power
  - Gradient of wind power and solar power feed in
- Load forecast error, load noise and gradient of load
- Outage of transmission and distribution elements

Day ahead and 4 hour ahead wind forecast and online data, positive / negative balancing power need

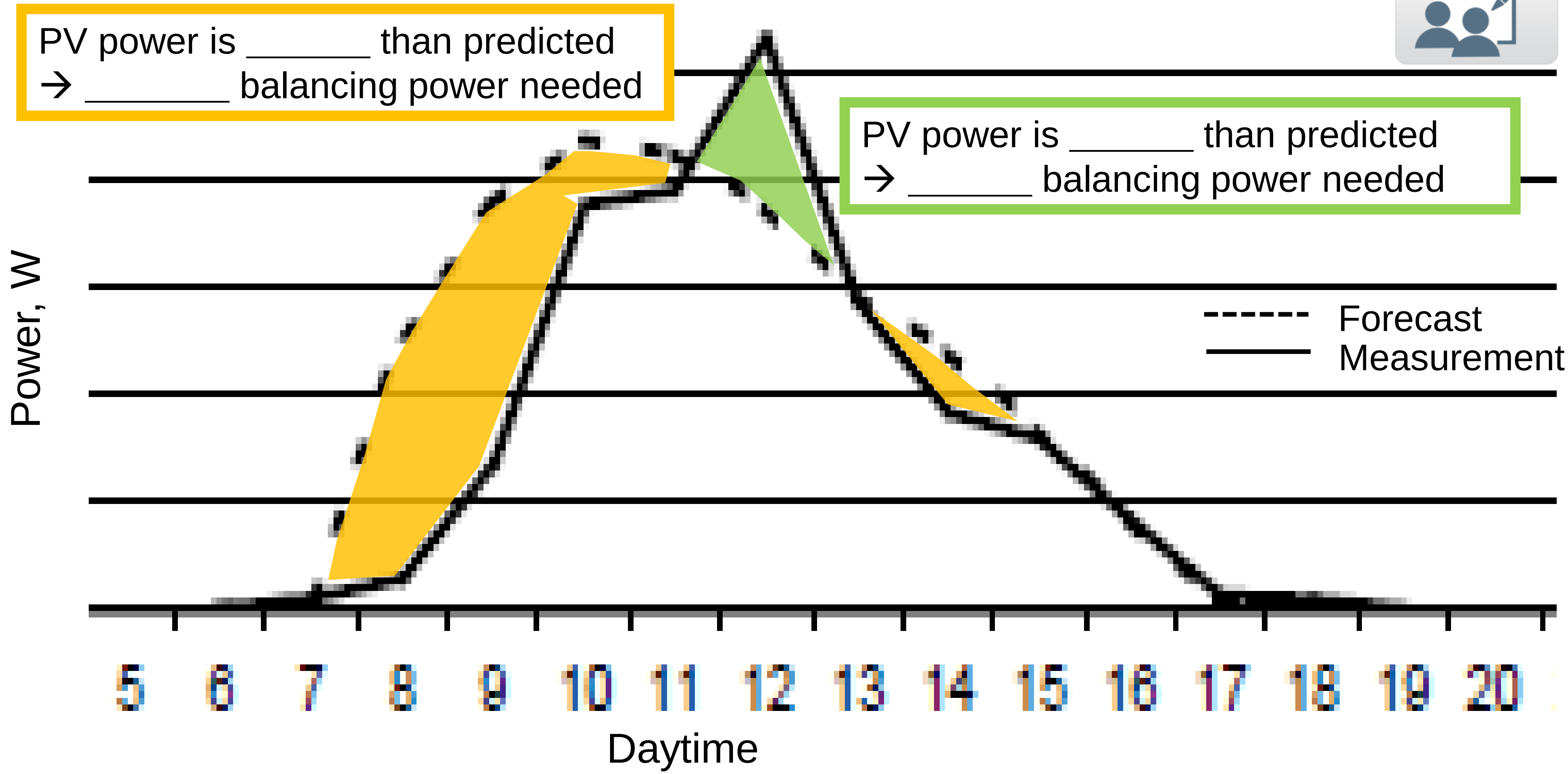


Source: ISET, 2003, supplemented

Source: dena-gridstudy 2005

Exercise: Which imbalances need positive and negative balancing power

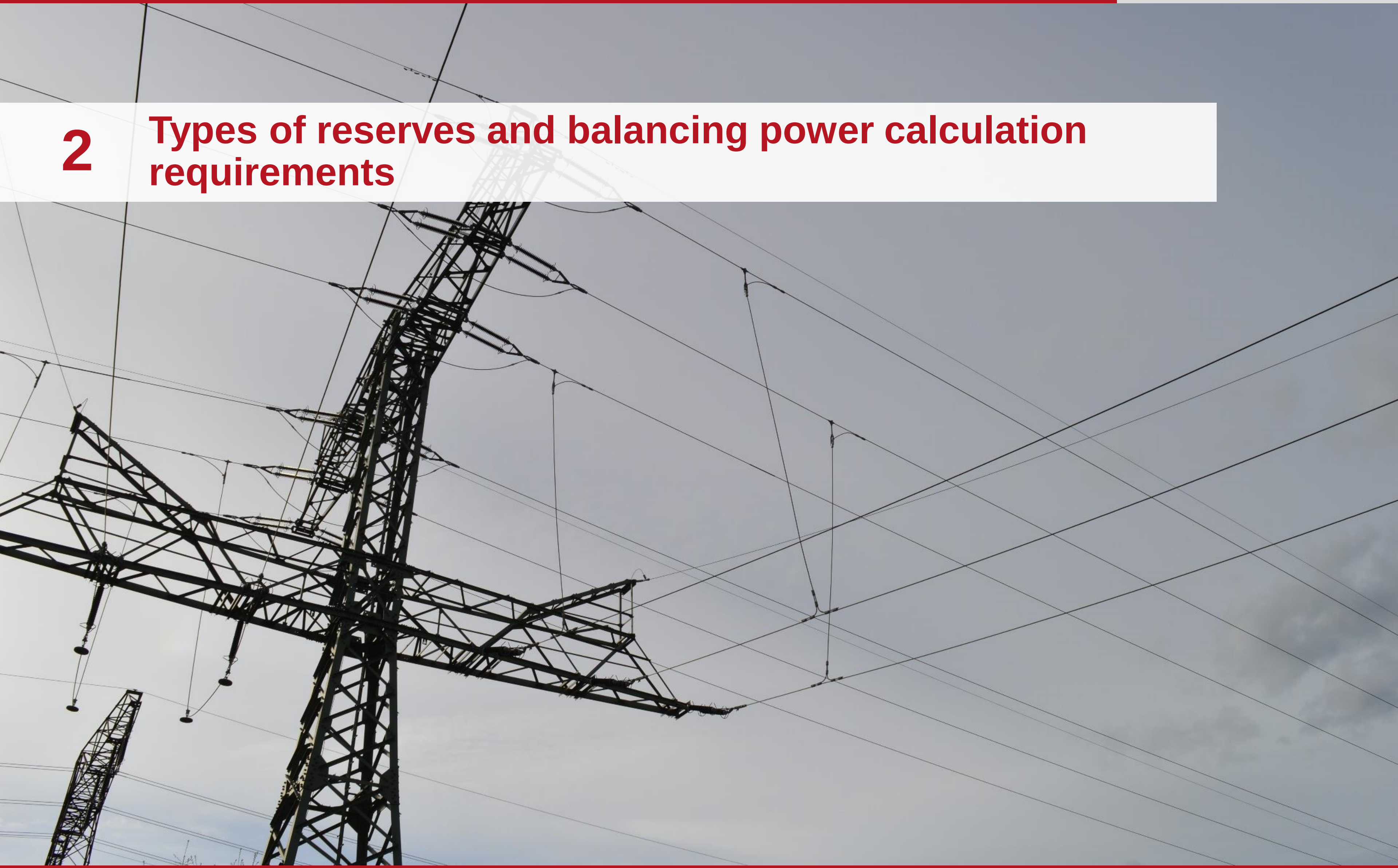
- PV day ahead forecast and online feed-in (measurement)



(with 50 – 100% cloud cover in Massachusetts, USA)

Source: Bing, 2005, explanaaiton and clulors added by RENAC

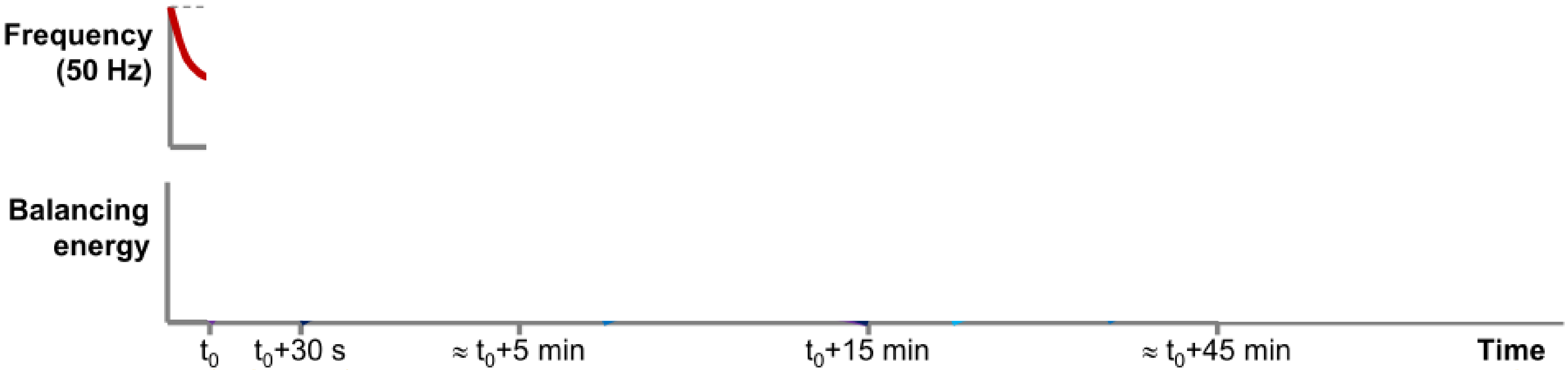
2 Types of reserves and balancing power calculation requirements



Types of reserves (Fast Containment Reserve, Frequency Restauration Reserve and Replacement Reserve)

renac renewables academy

FCR	aFRR	mFRR	RR
Automatic activation	Automatic activation	Semi-automatic or manual activation	Semi-automatic or manual activation
Up to 15 minutes	30s to 15 minutes	Minimum 15 min.	Minimum 15 min.

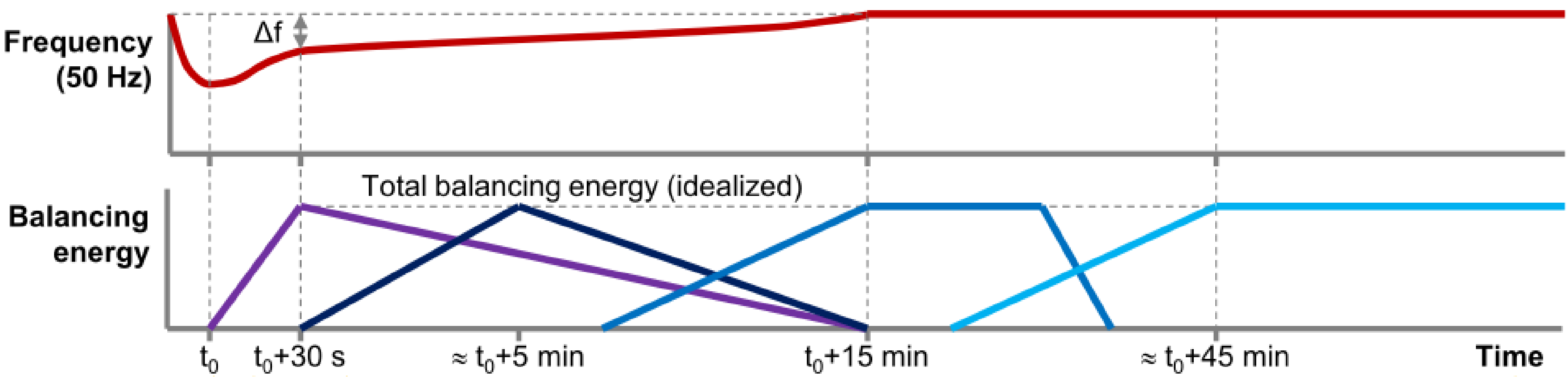


FCR = Fast Containment Reserve
aFRR = automatic Frequency Restauration Reserve
mFRR = manual Frequency Restauration Reserve
RR = Replacement Reserve

Kjell A Barmsnes, Convenor WG AS, ENTSO-E and Alexander Dusolt, Market Advisor, ENTSO-E: „ELECTRICITY BALANCING GUIDELINE AND IMPLEMENTATION “, page 15, 25 April 2017

Types of reserves (Fast Containment Reserve, Frequency Restauration Reserve and Replacement Reserve)

FCR	aFRR	mFRR	RR
Automatic activation	Automatic activation	Semi-automatic or manual activation	Semi-automatic or manual activation
Up to 15 minutes	30s to 15 minutes	Minimum 15 min.	Minimum 15 min.



FCR = Fast Containment Reserve
aFRR = automatic Frequency Restauration Reserve
mFRR = manual Frequency Restauration Reserve
RR = Replacement Reserve

Kjell A Barmsnes, Convenor WG AS, ENTSO-E and Alexander Dusolt, Market Advisor, ENTSO-E: „ELECTRICITY BALANCING GUIDELINE AND IMPLEMENTATION “, page 15, 25 April 2017

Balancing power needs – deterministic calculation

- Some system operators calculate the need for primary, secondary or tertiary reserve according to the largest power station in their control zone.
- Example
  - Ability to balance two very large power plant blackouts at the same time
  - Largest power plant capacity ca. 375 MW
  - Reserve = 2 x 375 MW = 750 MW
- Disadvantages of this approach are:
  - Over- or undersupply with reserves at certain times is not known
  - Power generation with wind and photovoltaic can not be included in the model

Source: **Continental Europe Operation Handbook, 2017**

Types of reserves (Fast Containment Reserve and Frequency Restauration Reserve)

renac renewables academy

	Primary reserve FCR	Secondary reserve aFRR	Tertiary reserve mFRR
Function			
Activation time			
Responsibility			
Dimensioning			

FCR = Fast Containment Reserve
aFRR = automatic Frequency Restauration Reserve
mFRR = manual Frequency Restauration Reserve
RR = Replacement Reserve

Source: Dr. Bade – r2b energy consulting GmbH, RENAC-Seminar, 2012

Types of reserves (Fast Containment Reserve and Frequency Restauration Reserve)

renac renewables academy

	Primary reserve FCR	Secondary reserve aFRR	Tertiary reserve mFRR
Function	Stopping and stabilising frequency deviations	- Return the frequency to its target value - Balance the deviations between control areas	
Activation time	< 30 s	< 5 min	< 15 min
Responsibility	Decentralized based on a solidarity principle within the synchronous area	Each system operator is technically and economically responsible for its own control area based on the 'user pays principle'	
Dimensioning	Administrative by the transmission code	**Probabilistic dimensioning methods**	

FCR = Fast Containment Reserve
aFRR = automatic Frequency Restauration Reserve
mFRR = manual Frequency Restauration Reserve
RR = Replacement Reserve

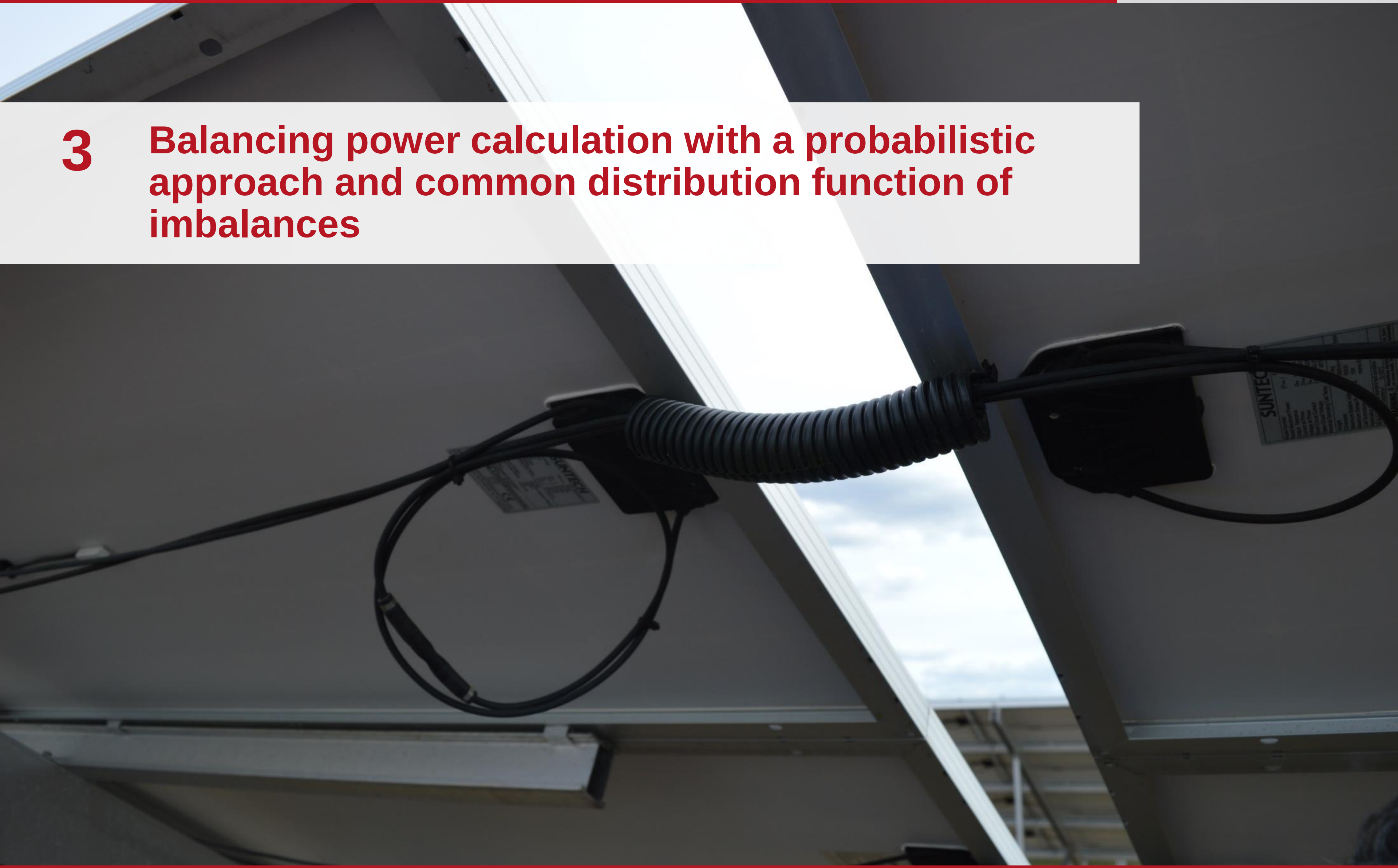
Source: Dr. Bade – r2b energy consulting GmbH, RENAC-Seminar, 2012

Input data for probabilistic balancing power dimensioning

renac renewables academy

- Probabilistic dimensioning of secondary (aFFR) and tertiary reserves (mFRR) should to take into account the following:
  - Short term forecast errors of wind power and solar power
  - Unexpected blackout of power stations and deviation from schedules
  - Load forecast error
  - Gradient of wind power and solar power feed in → residual load gradient
  - Deviation of power stations from planned schedule
  - Outage of transmission and distribution elements, and others

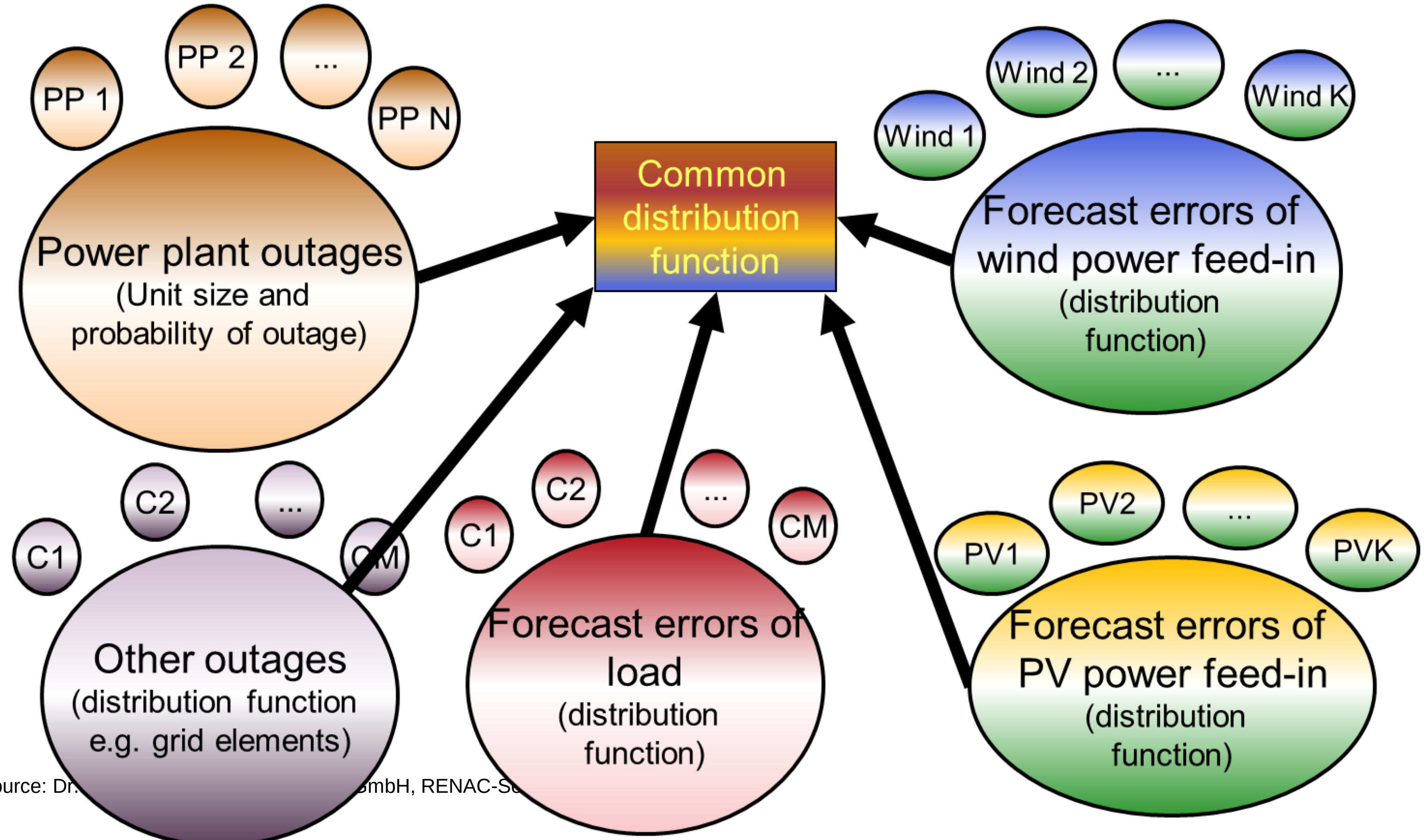
  - System reliability level that shall be achieved
  - Time specific data for dynamic calculation



3 Balancing power calculation with a probabilistic approach and common distribution function of imbalances

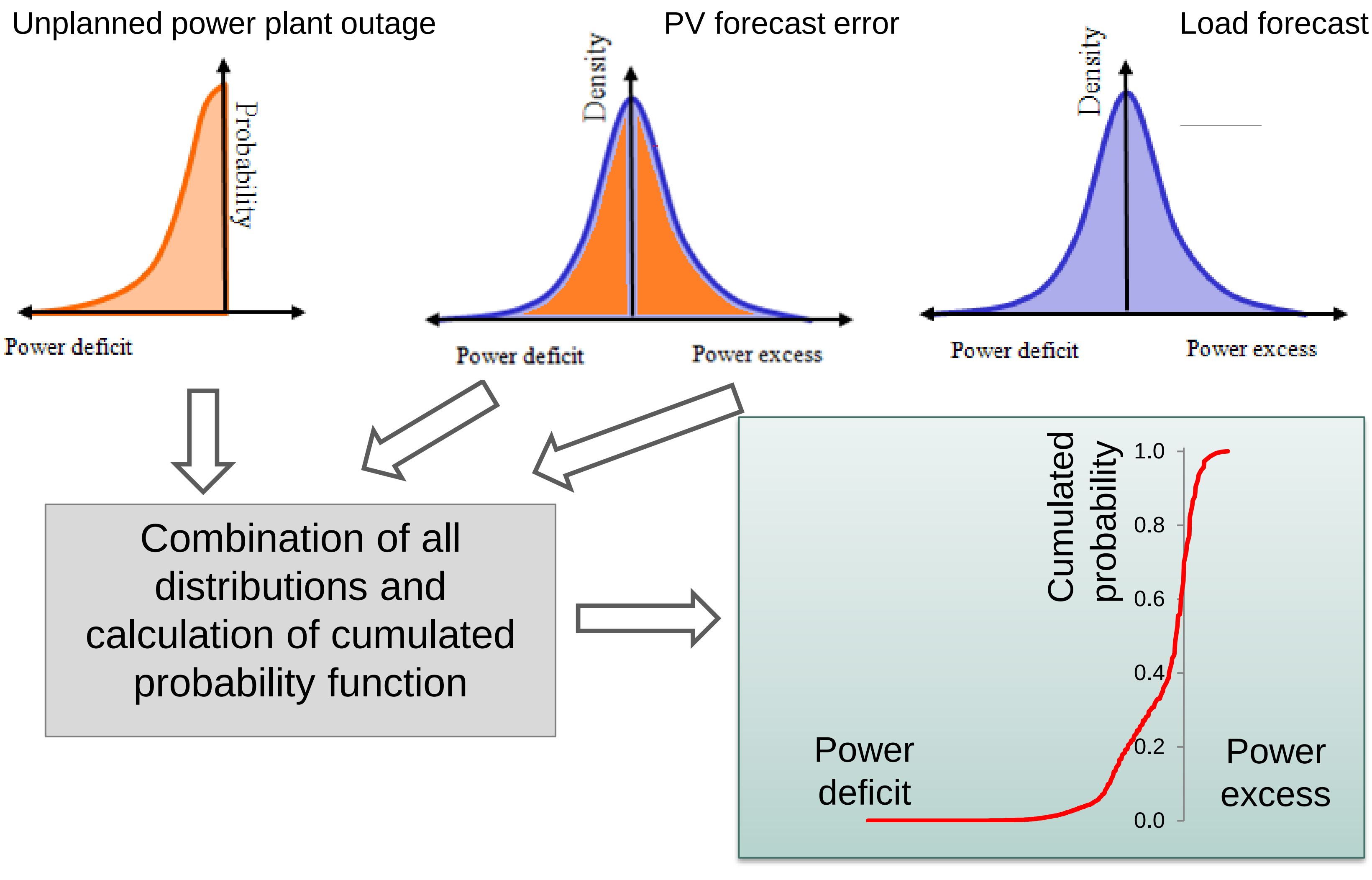
Common distribution function inputs

- Common distribution function combines different imbalance distributions
- The calculation of the cumulated imbalance distribution needs computational power and adequate algorithms



Source: Dr. … mbH, RENAC-S…

Overview - probabilistic balancing power calculation

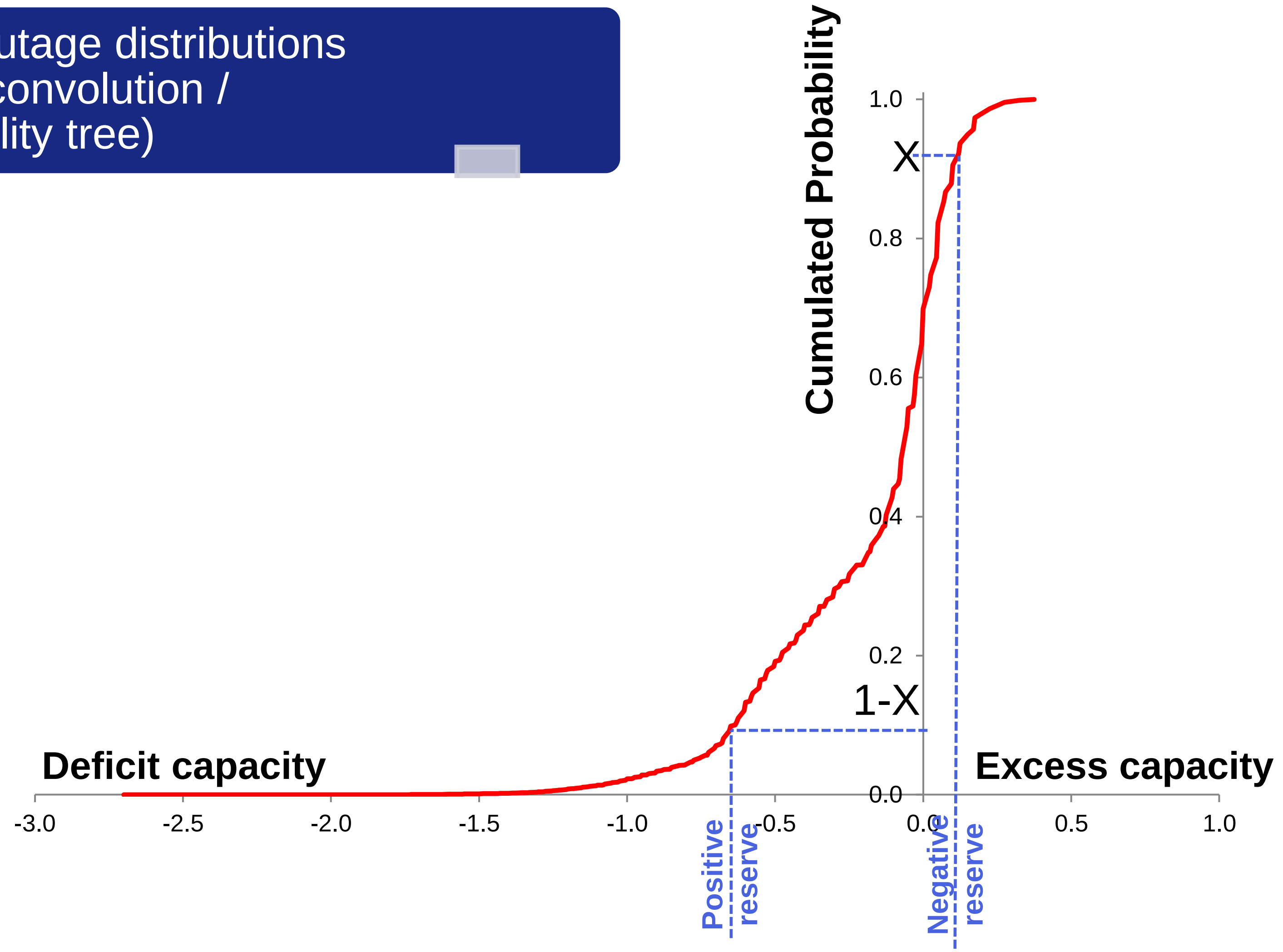


Source: Dr. Bade – r2b energy consulting GmbH, RENAC-Seminar, 2012 and RENAC 2015

Steps of probabilistic balancing power calculation methodology with reliability level

renac renewables academy

Combination of outage distributions
(recursive convolution /
probability tree)



Steps of probabilistic balancing power calculation methodology with reliability level

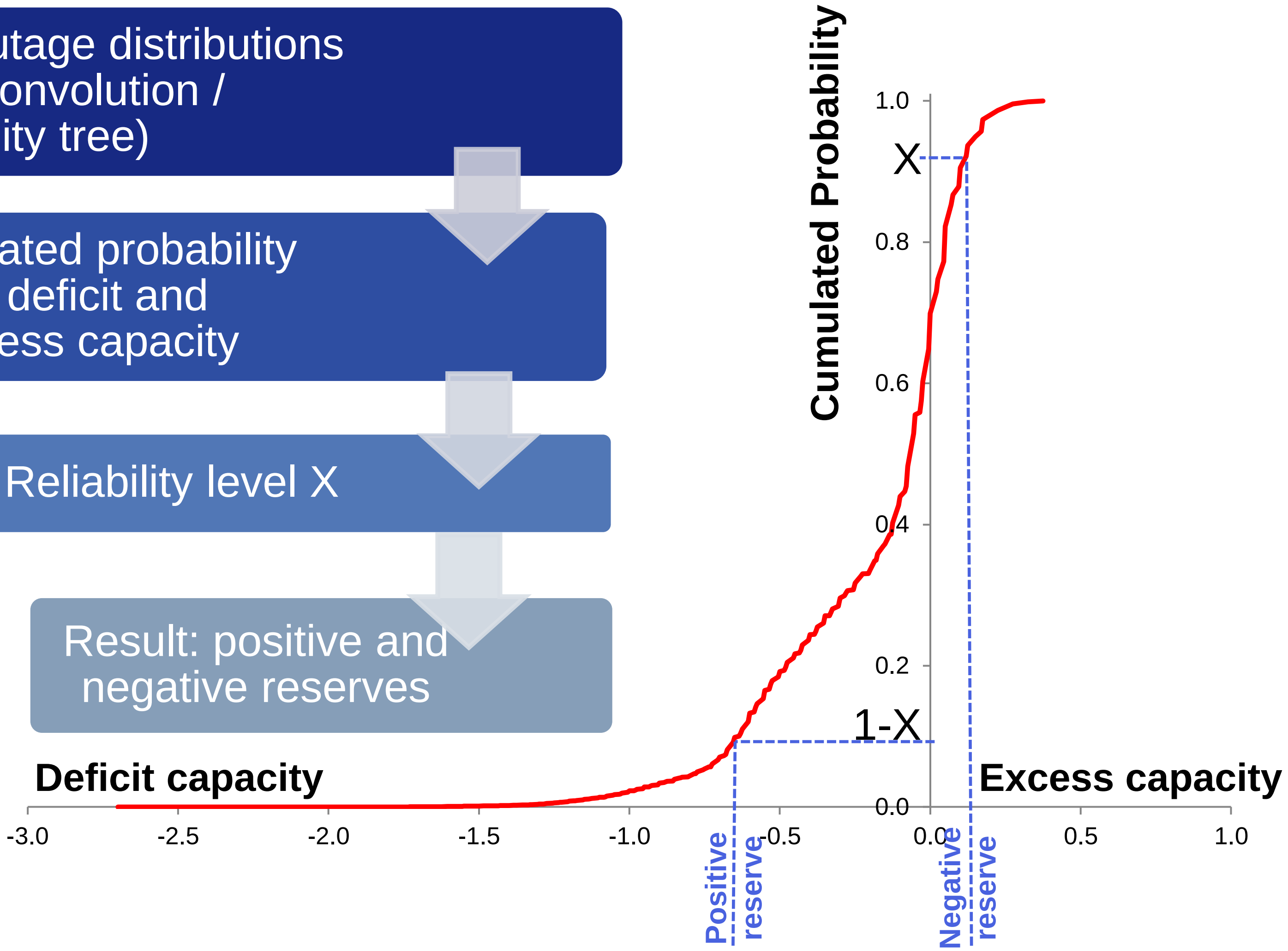
renac
renewables academy

Combination of outage distributions (recursive convolution / probability tree)

Cumulated probability of deficit and excess capacity

Reliability level X

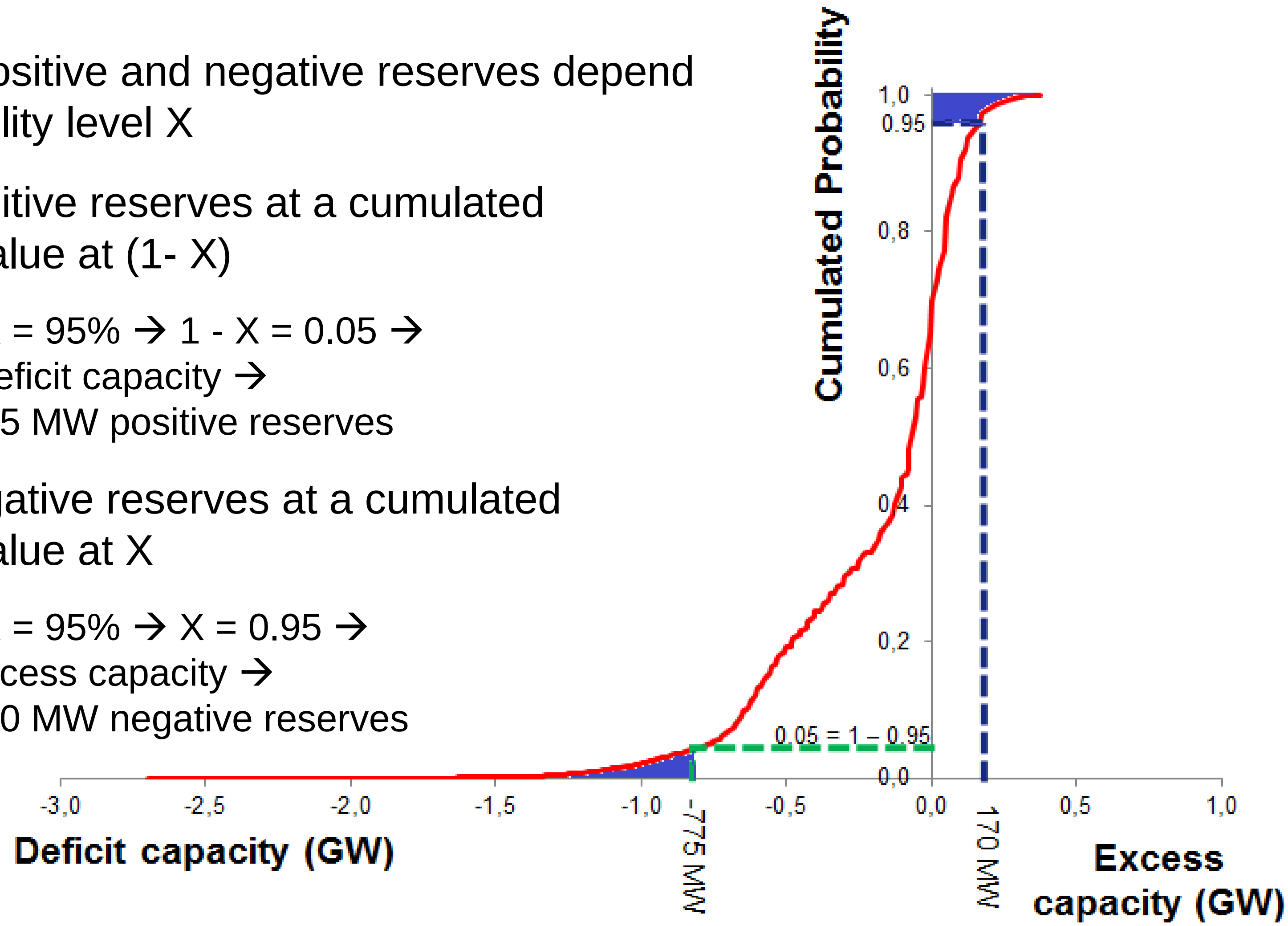
Result: positive and negative reserves



Reserve calculation with cumulated outage and excess capacity, cumulated probability and reliability level

renac renewables academy

- Amount of positive and negative reserves depend on the reliability level X
- Need for positive reserves at a cumulated probability value at (1- X)
  - Example: X = 95% → 1 - X = 0.05 → -775 MW deficit capacity → need for 775 MW positive reserves
- Need for negative reserves at a cumulated probability value at X
  - Example: X = 95% → X = 0.95 → 170 MW excess capacity → need for 170 MW negative reserves



3a Power plant outage distribution

Definition of the power plant outage distribution

renac renewables academy

- To understand the properties of the aggregated power plant outages, we need to understand the outage probabilities of each power plant.
- Definition outage probability
  The outage probability of a power plant is defined as the unplanned and undispatchable non-availability of a power plant within a given time frame.
- Outage probability can empirically be found by analyzing the failure statistics of individual power plants.
- Additionally, we need a probability model that transforms the failure statistics into an outage probability.

Source: Dr. Bade – r2b energy consulting GmbH, RENAC-Seminar, 2012

Power plant outage model: Markov Process

renac renewables academy

- A simple outage model of power plants is a two-state homogenous Markov-Process:
  - State A: The power plant is running $E[T_A]$ is the average time (in hours), a power plant operates without any failure
  - State B: The power plant drops out $E[T_B]$ is the average time (in hours), a power plant is out of order
- Assumptions:
  - Drop-out rate is independent from time and constant
  - The lifetime of a power plant equals infinity (this is just a mathematical assumption of little relevance)
- Result:
  - The resulting outage probabilities are time independent and can be expressed as a function of operation and outage times

Source: Dr. Bade – r2b energy consulting GmbH, RENAC-Seminar, 2012

Power plant outage model: Markov Process

- The probability of a power plant being in operation is Pr{A}
- The probability of being out of order is Pr{B}

$$Pr\{A\} = \frac{E[T_A]}{E[T_A] + E[T_B]}$$

$$Pr\{B\} = \frac{E[T_B]}{E[T_A] + E[T_B]}$$

With:

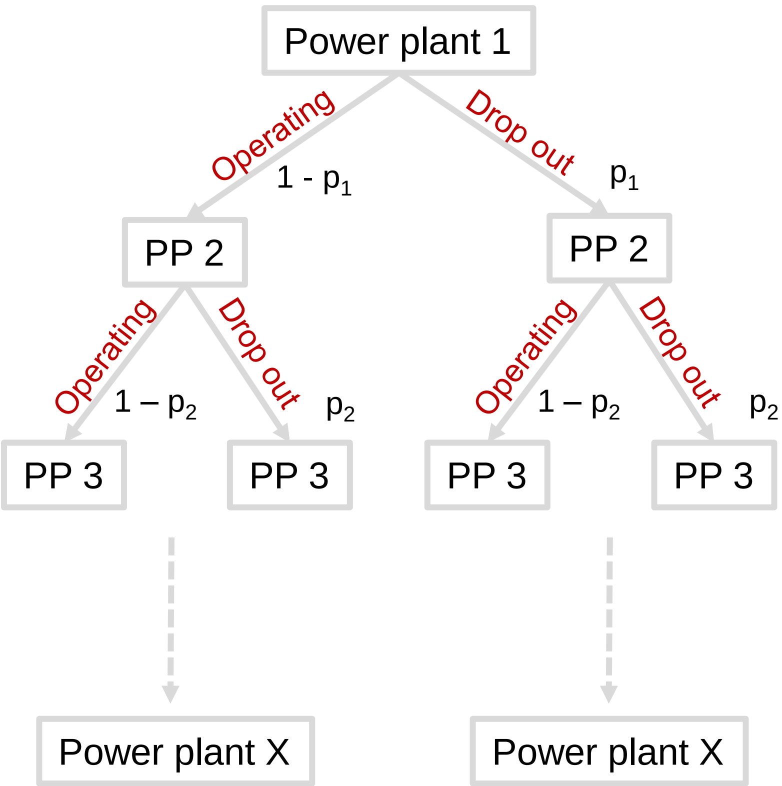
- Power plant is running E[TA]
- Power plant drops out E[TB]

.

Source: Dr. Bade – r2b energy consulting GmbH, RENAC-Seminar, 2012

VGB (2006): Analyse der Nichtverfügbarkeit von Wärmekraftwerken 1996 – 2005, VGB PowerTech e. V., Essen, 2006

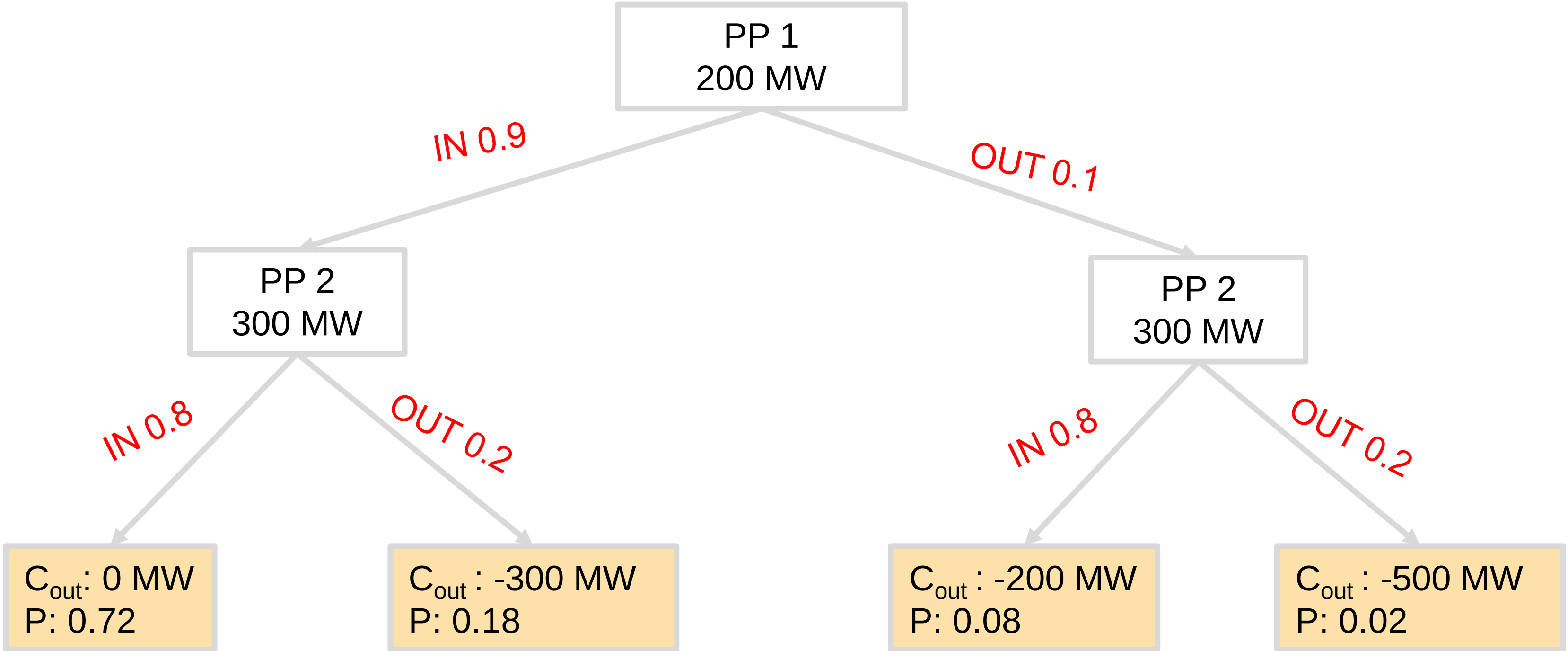
Power plant outage tree methodology



- All possible combinations of power plant drop-outs are calculated. Each resulting state is characterized by a total failed capacity and a (cumulated) probability of occurrence
- Each power plant *i* is characterized by an outage probability p_i and an installed capacity c_i
- With the probability p_i the capacity c_i becomes unavailable
- The tree has 2^n nodes (simplifications in the search process are possible to reduce complexity)
- Large power generation systems need computational power to calculate the tree

Source: Dr. Bade – r2b energy consulting GmbH, RENAC-Seminar, 2012

Outage probability tree for two power stations



PP = Power plant
C_{out} = Capacity outage (MW)
R = Reserve (MW)

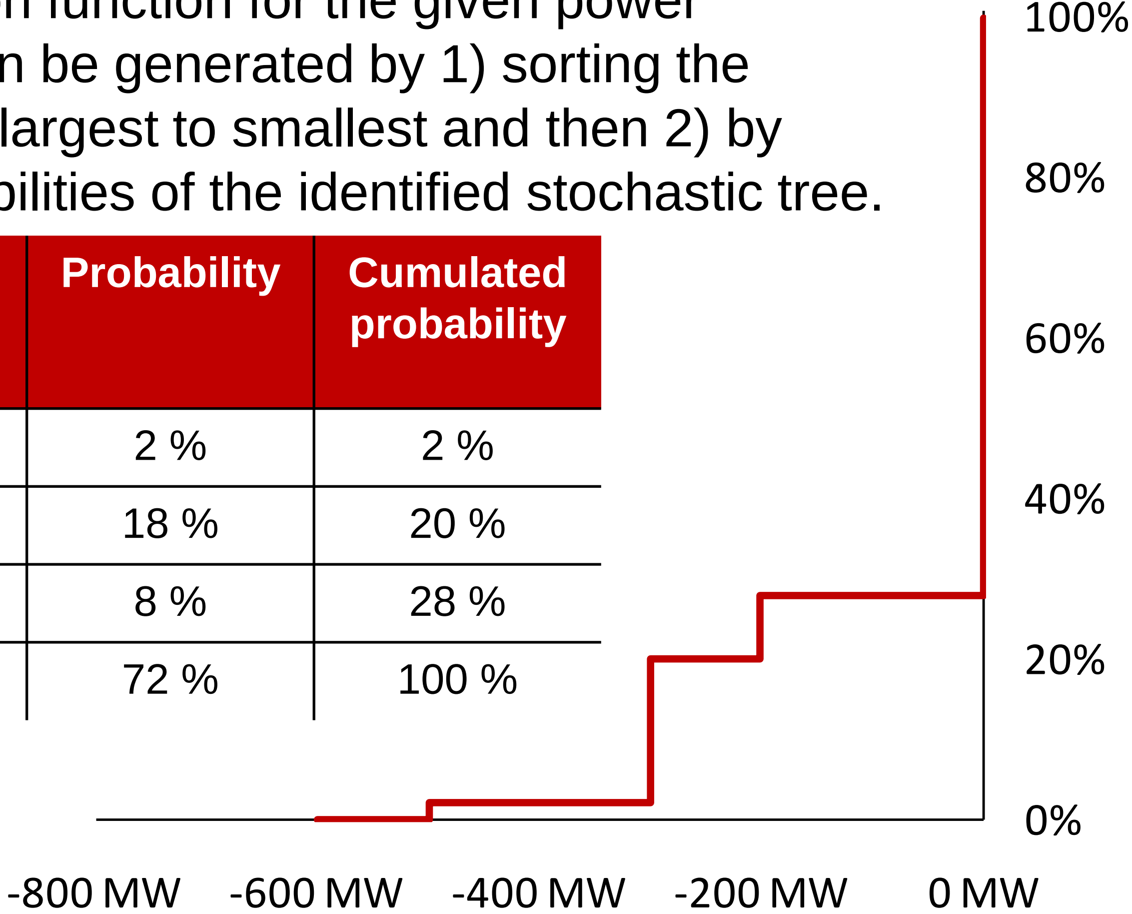
P = Probability (1 = 100%)
IN = PP in operation
OUT = PP out of operation

Source: Dr. Bade – r2b energy consulting GmbH, RENAC-Seminar, 2012

Cumulated outage distribution for two power stations

- The outage distribution function for the given power generation system can be generated by 1) sorting the outage capacity from largest to smallest and then 2) by cumulating the probabilities of the identified stochastic tree.

Tree (O=out, I=In)	Sorted outage capacity	Probability	Cumulated probability
OO	- 500 MW	2 %	2 %
IO	- 300 MW	18 %	20 %
OI	- 200 MW	8 %	28 %
II	0 MW	72 %	100 %



Source: Dr. Bade – r2b energy consulting GmbH, RENAC-Seminar, 2012

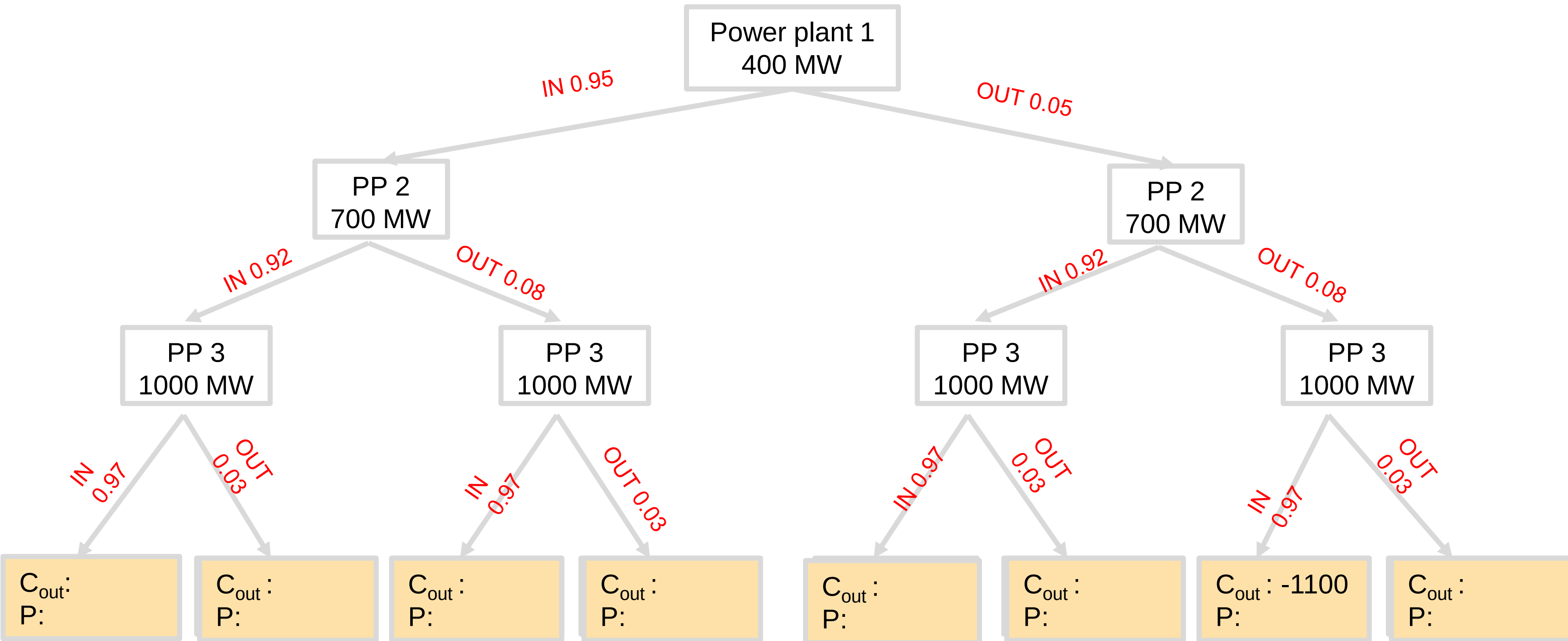
Exercise: Cumulated outage distribution graph for three power stations

renac
renewables academy

- A fictitious small country has only three thermal power plants. The three plants have the following capacities and outage probabilities:
  - Power plant 1: 400 MW, outage probability 5%
  - Power plant 2: 700 MW, outage probability 8%
  - Power plant 3: 1000 MW, outage probability 3%
- To do´s:
  - Draw the probability tree for the three plants on paper
  - Calculate probabilities and outage capacity for each node in the tree and write the probabilities on the respective place in the probability tree
  - Sort the outage capacity from largest to smallest
  - Calculate the cumulated outage probability for each outage combination

Source: Renac, 2015

Exercise: Probability tree



PP = Power plant
C_{out} = Capacity outage (MW)
R = Reserve (MW)

P = Probability (1 = 100%)
IN = PP in operation
OUT = PP out of operation

Source: Renac, 2015

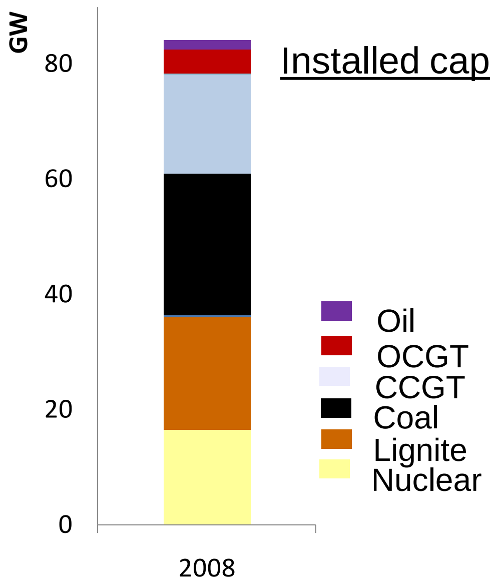
Exercise: Cumulated outage probability

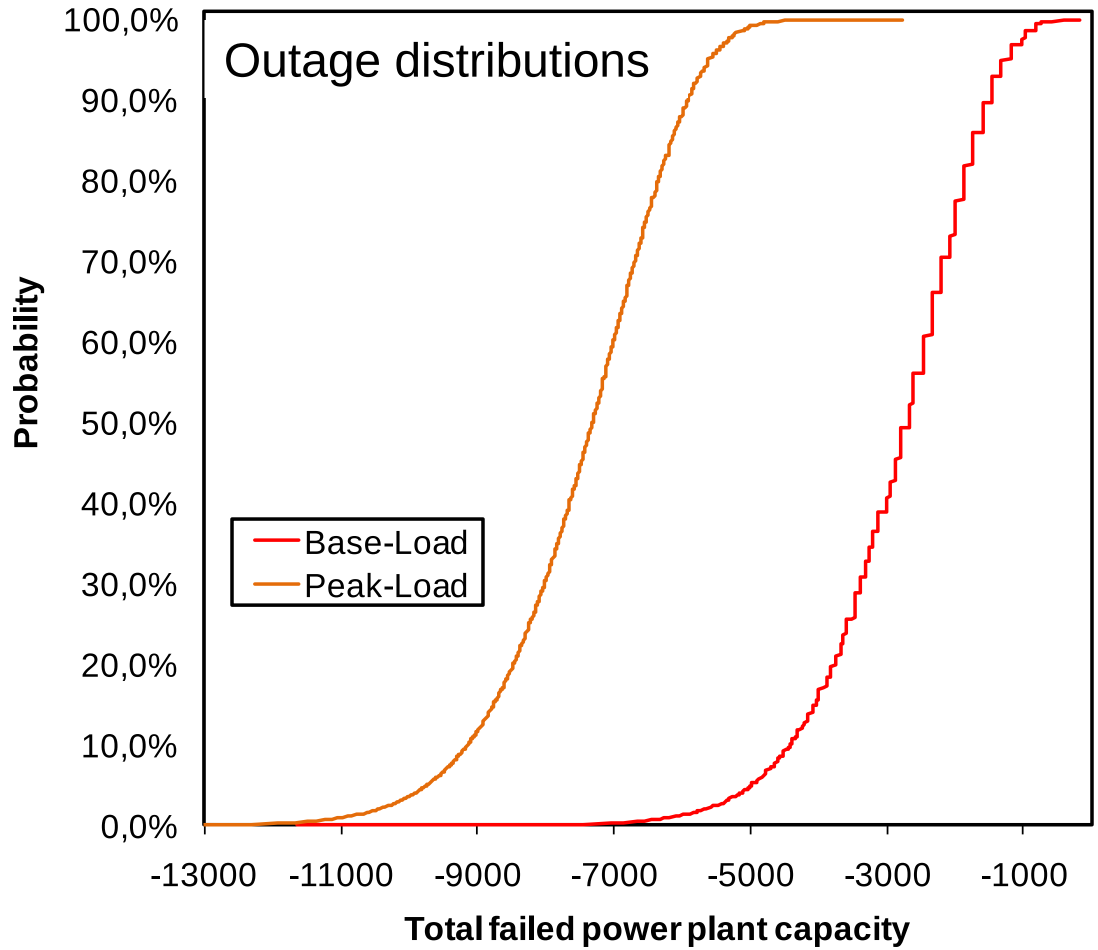
Power station i = in, o = out	Probability	Outage capacity (MW)	Cumulated outage probability
ooo			
ioo			
oio			
ooi			
iio			
ioi			
oii			
iii			

Source: Renac, 2015

Example: Outage distributions for a system with 40 GW off peak and 80 GW peak load

- Power plant data set consists of 723 generation units.
- Case 'base-load': ~ 40 GW of power plants connected to cover the base load
- Case 'peak-load': ~ 80 GW of power plants connected to cover peak load

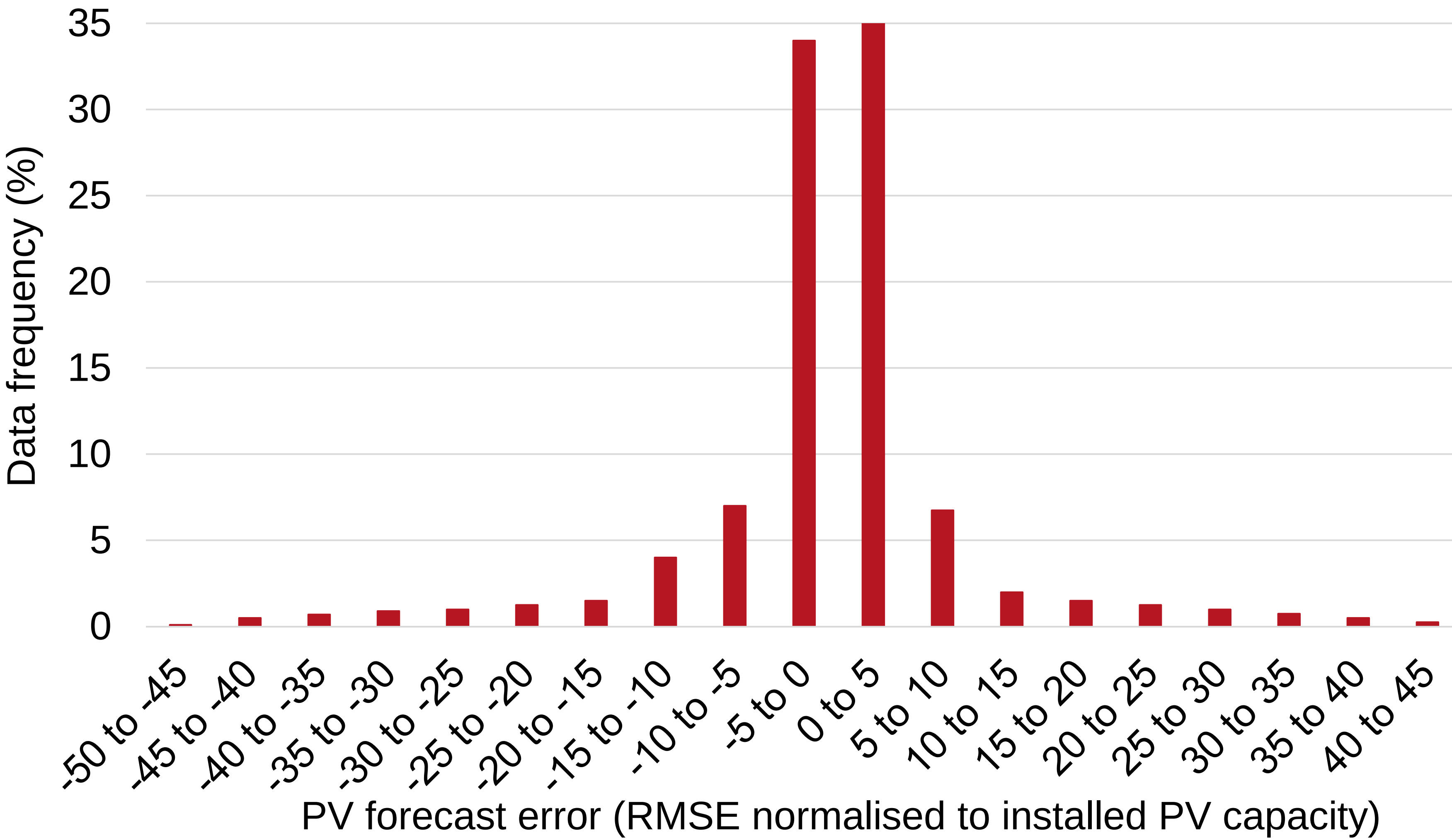




Source: Dr. Bade – r2b energy consulting GmbH, RENAC-Seminar, 2012

PV Forecast error distribution

PV forecast error distribution example

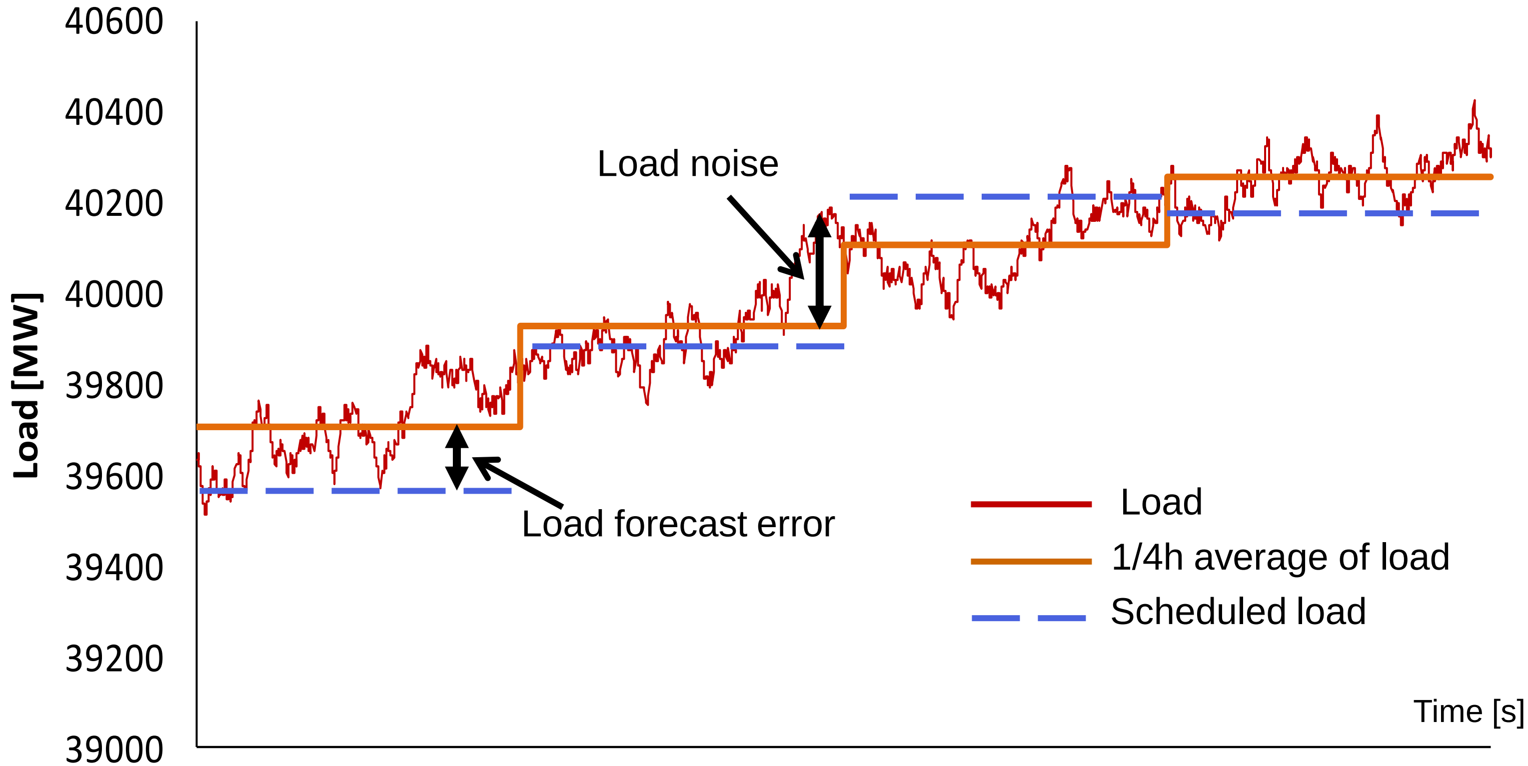


Soure: internal data

3b Load forecast error distribution

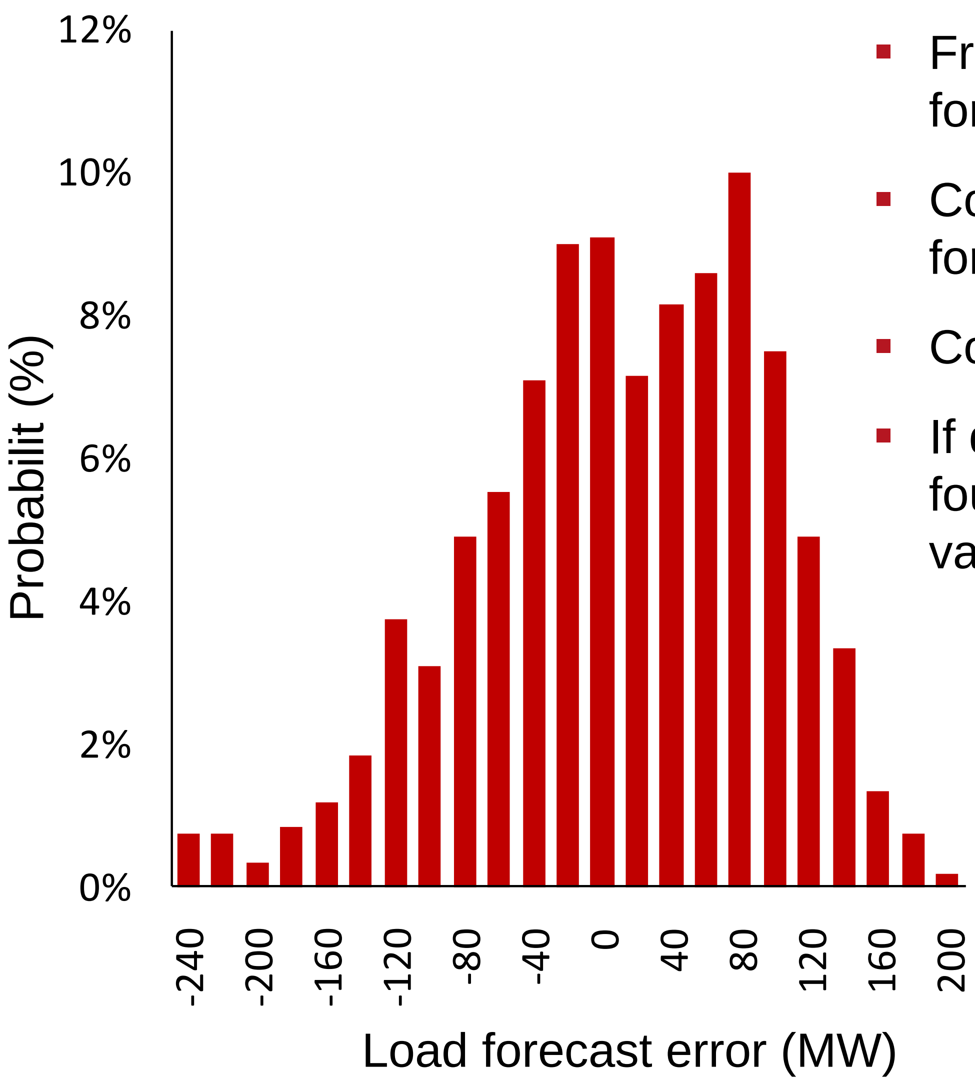
Load forecast errors and load noise

- **Load noise** is the difference between the load at a specific moment and the average of load in the respective 15 minute interval
- **Load forecast error** is the difference between the scheduled load and the average of measured load in a 15 minute interval



Source: Dr. Bade – r2b energy consulting GmbH, RENAC-Seminar, 2012

Load forecast error distribution example



- From empirical values, build the load forecast distribution function
- Count the frequency of each load forecast within a given range
- Construct the empirical histogram
- If desired, an analytical form can be found by interpolating the empirical values

Minus = Underestimation of load
Plus = Overestimation of load

Source: Dr. Bade – r2b energy consulting GmbH, RENAC-Seminar, 2012

4 Balancing power calculation with probabilistic approach - exercises with excel tool

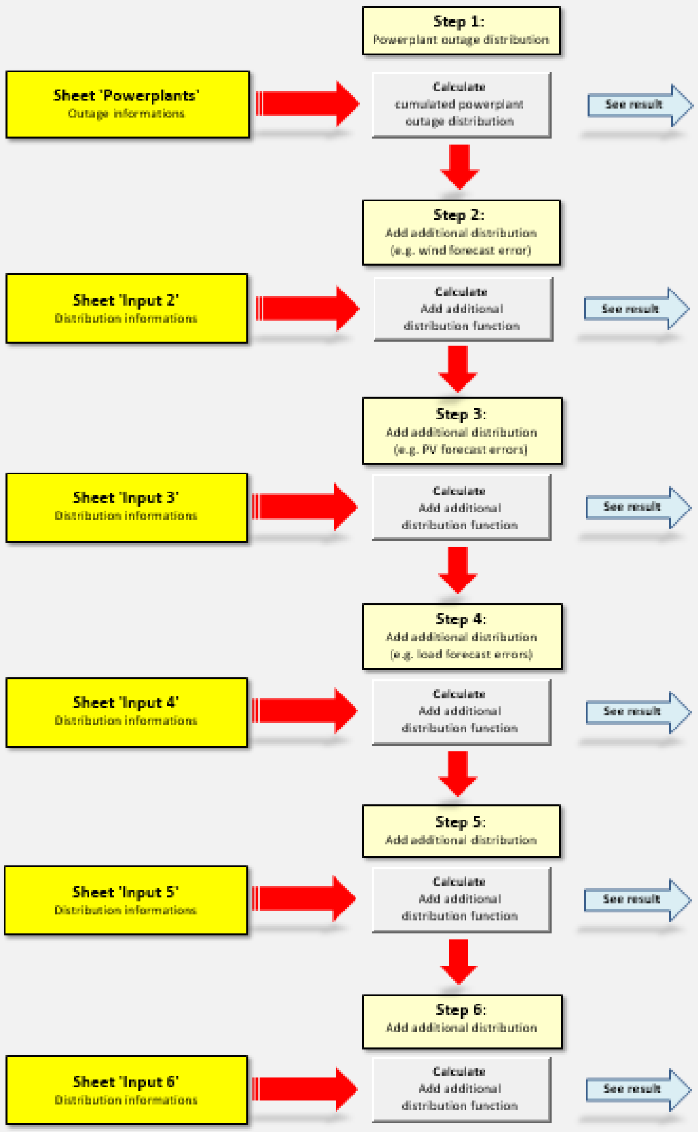
Balancing power calculation Excel tool

- Input:
  - Power station outage distribution (up to 100 power stations)
  - Wind forecast error distribution
  - PV Forecast error distribution
  - Load forecast error distribution and further distributions
  - Reliability level (power outage / excess power)
  - Output:
    - Power outage → positive reserve
    - Excess power → negative reserve

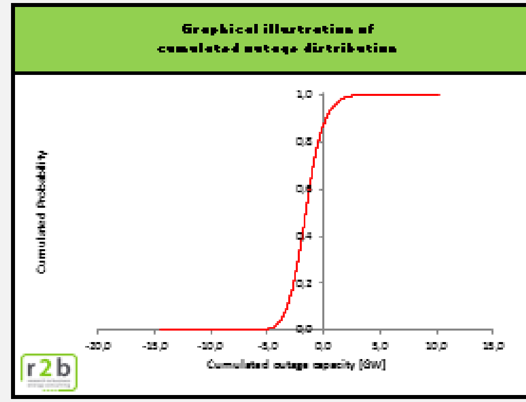
Cumulated distribution - general calculation procedure

1. Enter the power plants and their outage probabilities into the sheet "Powerplants"
2. Calculate the cumulated power plant outage distribution
3. Enter the first additional distribution (e.g. wind forecast error) into the sheet "Input 2" (or whatever its name is)
4. Calculate the cumulated imbalance distribution by adding the first additional distribution
5. Perform step 3 and 4 for up to four other additional distributions (e.g. PV or load forecast errors) by using the sheets "Input 3" to "Input 6"

Main sheet - control area (left) and result area (right)



Cumulated Distribution		
Outage	Density	Cumulation
-14.440,0 MW	0,00%	0,00%
-14.430,0 MW	0,00%	0,00%
-14.428,0 MW	0,00%	0,00%
-14.427,0 MW	0,00%	0,00%
-14.425,0 MW	0,00%	0,00%
-14.423,0 MW	0,00%	0,00%
-14.422,0 MW	0,00%	0,00%
-14.420,0 MW	0,00%	0,00%
-14.419,0 MW	0,00%	0,00%
-14.418,0 MW	0,00%	0,00%
-14.417,0 MW	0,00%	0,00%
-14.416,0 MW	0,00%	0,00%
-14.415,0 MW	0,00%	0,00%
-14.413,0 MW	0,00%	0,00%
-14.412,0 MW	0,00%	0,00%
-14.411,0 MW	0,00%	0,00%
-14.410,0 MW	0,00%	0,00%
-14.409,0 MW	0,00%	0,00%
-14.408,0 MW	0,00%	0,00%
-14.407,0 MW	0,00%	0,00%
-14.406,0 MW	0,00%	0,00%
-14.405,0 MW	0,00%	0,00%
-14.404,0 MW	0,00%	0,00%
-14.403,0 MW	0,00%	0,00%
-14.402,0 MW	0,00%	0,00%
-14.401,0 MW	0,00%	0,00%
-14.400,0 MW	0,00%	0,00%
-14.399,0 MW	0,00%	0,00%
-14.398,0 MW	0,00%	0,00%
-14.397,0 MW	0,00%	0,00%
-14.396,0 MW	0,00%	0,00%
-14.395,0 MW	0,00%	0,00%
-14.394,0 MW	0,00%	0,00%
-14.393,0 MW	0,00%	0,00%
-14.392,0 MW	0,00%	0,00%
-14.391,0 MW	0,00%	0,00%
-14.390,0 MW	0,00%	0,00%
-14.389,0 MW	0,00%	0,00%
-14.388,0 MW	0,00%	0,00%
-14.387,0 MW	0,00%	0,00%
-14.386,0 MW	0,00%	0,00%
-14.385,0 MW	0,00%	0,00%
-14.384,0 MW	0,00%	0,00%
-14.383,0 MW	0,00%	0,00%
-14.382,0 MW	0,00%	0,00%
-14.381,0 MW	0,00%	0,00%
-14.380,0 MW	0,00%	0,00%
-14.379,0 MW	0,00%	0,00%
-14.378,0 MW	0,00%	0,00%
-14.377,0 MW	0,00%	0,00%
-14.376,0 MW	0,00%	0,00%
-14.375,0 MW	0,00%	0,00%
-14.374,0 MW	0,00%	0,00%
-14.373,0 MW	0,00%	0,00%
-14.372,0 MW	0,00%	0,00%
-14.371,0 MW	0,00%	0,00%



Tree nodes	24.703

Security level		Reserve Power
Power Outage	10,0%	3.252 MW
Excess Power	90,0%	219 MW

Balancing power calculation Excel tool

- Input:
  - Reliability level X:
    - Power Outage Probability = 100 - X
    - Excess power probability = X

Reliability level		Power
Power Outage	10,0%	238 MW
Excess Power	90,0%	200 MW

100 - X

X

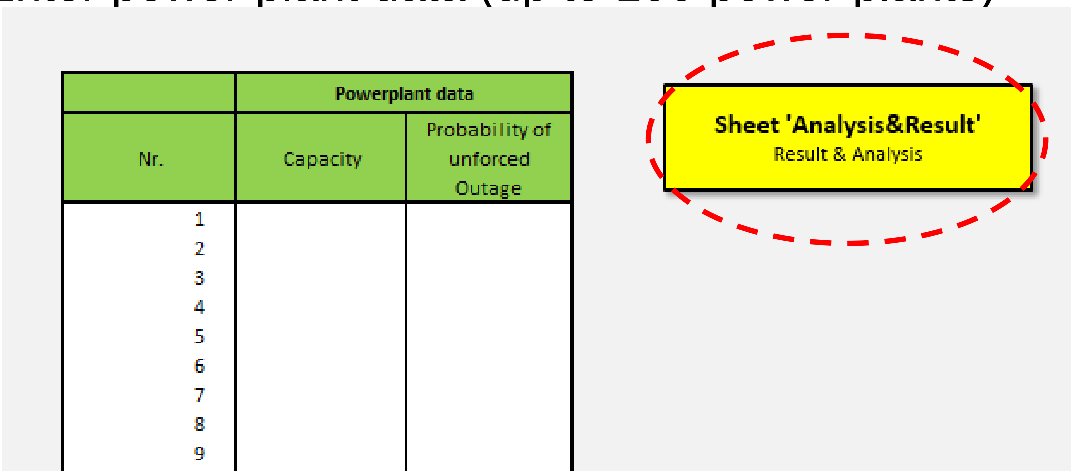
Result: deficit capacity at a certain reliability level

Result: excess capacity at a certain reliability level

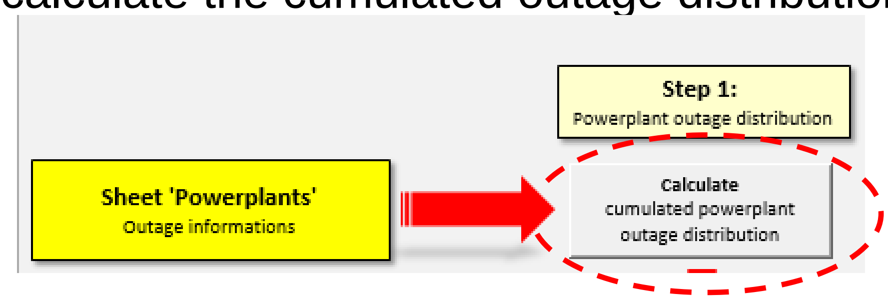
Step 1: Adding power plants

renac
renewables academy

- Enter power plant data (up to 100 power plants)



- When you have finished adding your power plants, klick the yellow button to return to the sheet “Analysis&Results”. Press “Calculate” button to calculate the cumulated outage distribution.



Sign of load and wind /PV forecast error

- Load forecast error:
  - **Positive** values mean that less power is consumed than predicted and this means that additional power station capacity is available. (→ add positive numbers to excel tool)
  - **Negative** values mean that more power is consumed than predicted and the power generation capacity is less than predicted. (→ add negative numbers to excel tool)
- Wind and PV forecast error:
  - **Positive** values mean that wind / PV power is overestimated and this means that less power is available than prediceted. This is comparable to an unexpected black-out of a power station (→ add negative numbers to excel tool)
  - **Negative** values mean that wind / PV power is underestimated and this means that more power is available than prediceted. (→ add positive numbers to excel tool)

4a Exercises 1 and 2

Balancing power exercises 1 and 2

- Calculate the positive and negative balancing power needs for a reliability level of 95% and 99.9%.
- Exercise 1:
  - Assume 20 power stations with a capacity of 100 MW to 450 MW. The next two slide shows data of the power stations' capacity and outage probability.
  - Assume a PV forecast error and load forecast error according to the following slides.
- Exercise 2:
  - Change the power stations. Assume only 10 power stations. Please combine power station 1+2, 3+4…19+20. Note that total capacity remains unchanged. All probabilities are the same, as the individual plants.
  - Keep the PV forecast and load forecast data constant (same as in exercise 1)

Exercises 1 and 2: Probabilistic balancing power calculation (power stations, PV and load)

95% Reliability	Positive balancing power	Negative balancing power
System 1 with 20 medium size power stations	MW	MW
System 2 with 10 large power stations	MW	MW

99.9% Reliability	Positive balancing power	Negative balancing power
System 1 with 20 medium size power stations	MW	MW
System 2 with 10 large power stations	MW	MW

Exercise 1 - input dat for 20 power stations

Power station input data:

- thermal power plant 1: 150 MW, outage probability 5%
- thermal power plant 2: 150 MW, outage probability 5%
- thermal power plant 3: 200 MW, outage probability 8%
- thermal power plant 4: 200 MW, outage probability 8%
- thermal power plant 5: 200 MW, outage probability 3%
- thermal power plant 6: 200 MW, outage probability 3%
- thermal power plant 7: 300 MW, outage probability 12%
- thermal power plant 8: 300 MW, outage probability 12%
- thermal power plant 9: 300 MW, outage probability 8%
- thermal power plant 10: 300 MW, outage probability 8%

Exercise 1 - input dat for 20 power stations

renac
renewables academy

Power station Input data:

- thermal power plant 11: 100 MW, outage probability 5%
- thermal power plant 12: 100 MW, outage probability 5%
- thermal power plant 13: 300 MW, outage probability 8%
- thermal power plant 14: 300 MW, outage probability 8%
- thermal power plant 15: 350 MW, outage probability 3%
- thermal power plant 16: 350 MW, outage probability 3%
- thermal power plant 17: 400 MW, outage probability 12%
- thermal power plant 18: 400 MW, outage probability 12%
- thermal power plant 19: 450 MW, outage probability 8%
- thermal power plant 20: 450 MW, outage probability 8%

Exercise 2 - input data for 10 power station

Input data:

- thermal power plant 1: 300 MW, outage probability 5%
- thermal power plant 2: 400 MW, outage probability 8%
- thermal power plant 3: 400 MW, outage probability 3%
- thermal power plant 4: 600 MW, outage probability 12%
- thermal power plant 5: 600 MW, outage probability 8%
- thermal power plant 6: 200 MW, outage probability 5%
- thermal power plant 7: 600 MW, outage probability 8%
- thermal power plant 8: 700 MW, outage probability 3%
- thermal power plant 9: 800 MW, outage probability 12%
- thermal power plant 10: 900 MW, outage probability 8%

Exercise 1 and 2 - PV forecast error distribution

Input data:

- Overestimation 250 MW: 3%
- Overestimation 150 MW: 7%
- Overestimation 45 MW: 16%
- Overestimation 25 MW: 26%

Add negative MW-values to the excel tool

- Underestimation 30 MW: 24%
- Underestimation 50 MW: 14%
- Underestimation 160 MW: 7%
- Underestimation 275 MW: 3%

Add positive MW-values to the excel tool

Exercise 1 and 2 - Load forecast error distribution

Input data:

- Overestimation 125 MW: 7%
- Overestimation 75 MW: 15%
- Overestimation 25 MW: 28%

Add positive MW-values to the excel tool

- Underestimation 25 MW: 28%
- Underestimation 75 MW: 15%
- Underestimation 125 MW: 7%

Add negative MW-values to the excel tool

4b Exercise 3

Exercise 3: Balancing power calculation (only power outages and load forecast error – no wind and no PV)

- Calculate the positive and negative balancing power needs for a reliability level of 95% and 99,9% for a power system with **3318 MW installed thermal capacity and two different outage probabilities but no PV generation.**
  - Scenario A
    - Assume power station outages for **scenario A**. The next two slides shows data of the power stations' capacity and outage probability A and B.
    - Use load forecast error data (next slide)
  - Scenario B
    - Assume power station outages for **scenario B**. The next two slides shows data of the power stations' capacity and outage probability A and B.
    - Use the same load forecast error as in scenario A.

Exercise 3: Probabilistic balancing power calculation (power stations and load error)

95% Reliability	Positive balancing power	Negative balancing po
System with scenario A power stations (without wind and PV)	MW	MW
System with scenario B power stations (without wind and PV)	MW	MW

99.9% Reliability	Positive balancing power	Negative balancing power
System with scenario A power stations (without wind and PV)	MW	MW
System with scenario B power stations (without wind and PV)	MW	MW

Exercise 3:
Power station outage assumption (scenario A and B)

Capacity (MW)	A-Outage probability (%)	B-Outage probability (%)
385.0 MW	5	1
319.0 MW	5	1
359.0 MW	5	1
105.0 MW	5	1
114.0 MW	5	1
114.0 MW	5	1
128.0 MW	5	1
132.0 MW	5	1
52.0 MW	5	1
100.0 MW	5	1
25.0 MW	5	1
100.0 MW	5	1
25.0 MW	5	1

Capacity (MW)	A-Outage probability (%)	B-Outage probability (%)
152.0 MW	5	1
70.0 MW	5	1
20.0 MW	5	1
49.0 MW	5	1
100.0 MW	5	1
100.0 MW	5	1
100.0 MW	5	1
90.0 MW	5	1
100.0 MW	5	1
35.0 MW	5	1
30.0 MW	5	1
50.0 MW	5	1
40.0 MW	5	1

Exercise 3:
Power station outage assumption (scenario A and B)

Capacity (MW)	A-Outage probability (%)	B-Outage probability (%)
60.0 MW	5	1
100.0 MW	5	1
50.0 MW	5	1
17.0 MW	5	1
180.0 MW	5	1
17.0 MW	5	1
17.0 MW	5	1
17.0 MW	5	1
17.0 MW	5	1
17.0 MW	5	1
17.0 MW	5	1
15.0 MW	5	1
25.0 MW	5	1
3318		

Exercise 3:
Load forecast error distribution

Average of Error bins (MW)	Percent of the year in the respective bin
475	0.01%
425	0.06%
375	0.10%
325	0.16%
275	0.27%
225	1.13%
175	4.06%
125	11.59%
75	19.45%
25	23.87%

Average of Error bins (MW)	Percent of time in the respective bin
-25	17.59%
-75	11.00%
-125	5.76%
-175	2.67%
-225	1.08%
-275	0.51%
-325	0.50%
-375	0.10%
-425	0.06%
-475	0.03%

4c Exercise 4

Exercise 4: Balancing power calculation (power outages + load + wind + PV forecast error)

- Calculate the positive and negative balancing power needs for a reliability level of 95% and 99.9% for a power system with **3318 MW installed thermal capacity and two different outage probilites.**
  - <u>Scenario A</u>
    - Assume power station outages for **scenario A**. The next two slides shows data of the power stations' capacity and outage probability A and B.
    - Use load forecast error, wind forecast error and PV forecast error data (next slide)
  - <u>Scenario B</u>
    - Assume power station outages for **scenario B**. The next two slides shows data of the power stations' capacity and outage probability A and B.
    - Use the same load forecast error, wind forecast error and PV forecast error data as in scenario A.

Exercise 4: Balancing power calculation (power outages + load + wind + PV forecast error)

95% Reliability	Positive balancing power	Negative balancing power
System with scenario A power stations	MW	MW
System with scenario B power stations	MW	MW

99,9% Reliability	Positive balancing power	Negative balancing power
System with scenario A power stations	MW	MW
System with scenario B power stations	MW	MW

Exercise 4:
Power station outage assumption (scenario A and B)

Capacity (MW)	A-Outage probability (%)	B-Outage probability (%)
385.0 MW	5	1
319.0 MW	5	1
359.0 MW	5	1
105.0 MW	5	1
114.0 MW	5	1
114.0 MW	5	1
128.0 MW	5	1
132.0 MW	5	1
52.0 MW	5	1
100.0 MW	5	1
25.0 MW	5	1
100.0 MW	5	1
25.0 MW	5	1

Capacity (MW)	A-Outage probability (%)	B-Outage probability (%)
152.0 MW	5	1
70.0 MW	5	1
20.0 MW	5	1
49.0 MW	5	1
100.0 MW	5	1
100.0 MW	5	1
100.0 MW	5	1
90.0 MW	5	1
100.0 MW	5	1
35.0 MW	5	1
30.0 MW	5	1
50.0 MW	5	1
40.0 MW	5	1

Exercise 4:
Power station outage assumption (scenario A and B)

Capacity (MW)	A-Outage probability (%)	B-Outage probability (%)
60.0 MW	5	1
100.0 MW	5	1
50.0 MW	5	1
17.0 MW	5	1
180.0 MW	5	1
17.0 MW	5	1
17.0 MW	5	1
17.0 MW	5	1
17.0 MW	5	1
17.0 MW	5	1
17.0 MW	5	1
15.0 MW	5	1
25.0 MW	5	1
3318		

Exercise 4:
Load forecast error distribution

Average of Error bins (MW)	Percent of the year in the respective bin
475	0.01%
425	0.06%
375	0.10%
325	0.16%
275	0.27%
225	1.13%
175	4.06%
125	11.59%
75	19.45%
25	23.87%

Average of Error bins (MW)	Percent of time in the respective bin
-25	17.59%
-75	11.00%
-125	5.76%
-175	2.67%
-225	1.08%
-275	0.51%
-325	0.50%
-375	0.10%
-425	0.06%
-475	0.03%

Positive error = Underestimation of load → add positive numbers to excel tool
Negative error = Underestimation of load → add negative numbers to excel tool

Exercise 4: Wind forecast error distribution

Average of Error bins (MW)	Percent of the year in the respective bin
130	0.01%
110	0.05%
90	0.76%
70	4.60%
50	11.35%
30	17.60%
10	27.31%

Average of Error bins (MW)	Percent of the year in the respective bin
-10	25.18%
-30	9.01%
-50	3.17%
-70	0.81%
-90	0.13%
-110	0.02%

Positive error = Overestimation of wind power → add negative numbers to excel tool
Negative error = Underestimation of wind power → add positive numbers to excel tool

Source: Load and load forecast error data Yeulis Rivas <yrivas@cne.gob.do, mail from 7 May 2019; own calculation

Exercise 4:
PV forecast error distribution

renac renewables academy

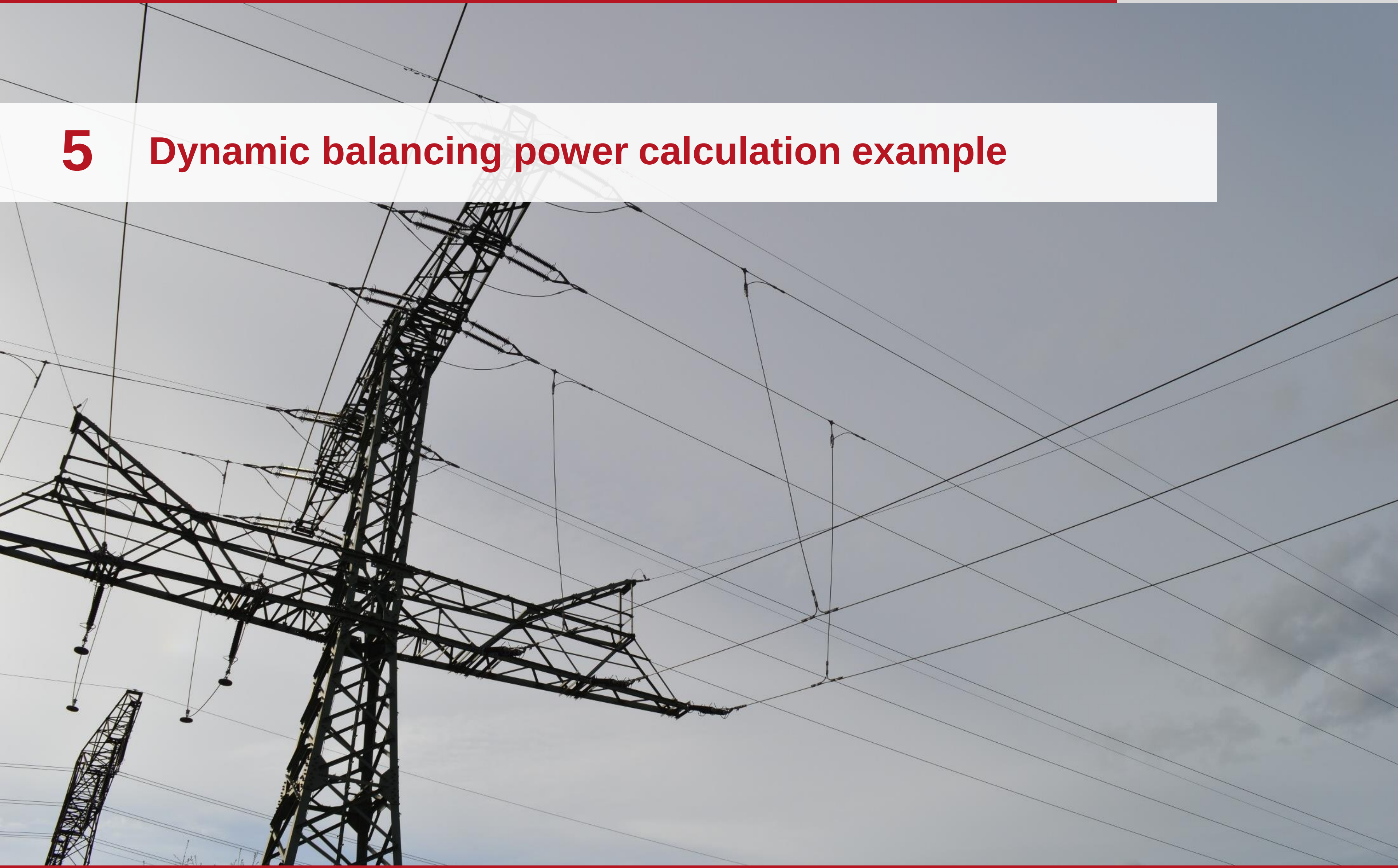
Average of Error bins (MW)	Percent of the year in the respective bin
45	0.02%
40	0.17%
35	0.87%
30	2.17%
25	2.82%
20	8.05%
15	16.45%
10	26.69%
5	22.82%

Average of Error bins (MW)	Percent of the year in the respective bin
-5	10.61%
-10	4.92%
-15	2.36%
-20	1.09%
-25	0.55%
-30	0.17%
-35	0.10%
-40	0.12%
-45	0.02%

Positive error = Overestimation of PV power → add negative numbers to excel tool
Negative error = Underestimation of PV power → add positive umbers to excel tool

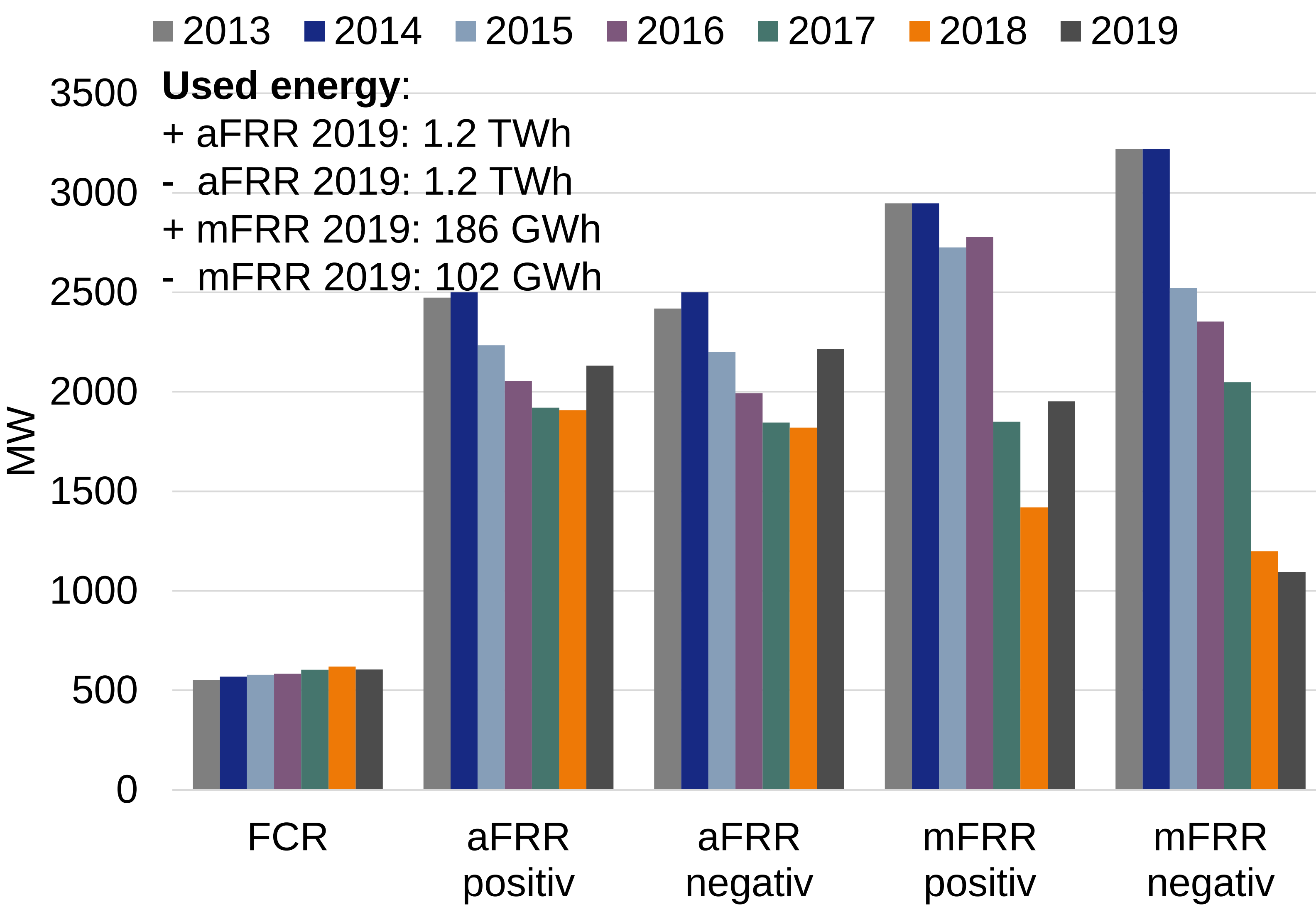
Source: Load and load forecast error data Yeulis Rivas <yrivas@cne.gob.do, mail from 7 May 2019; own calculation

5 Dynamic balancing power calculation example



Development of balancing power call for tender in Germany from 2013 to 2017 (MW, maximum per year)

renac renewables academy



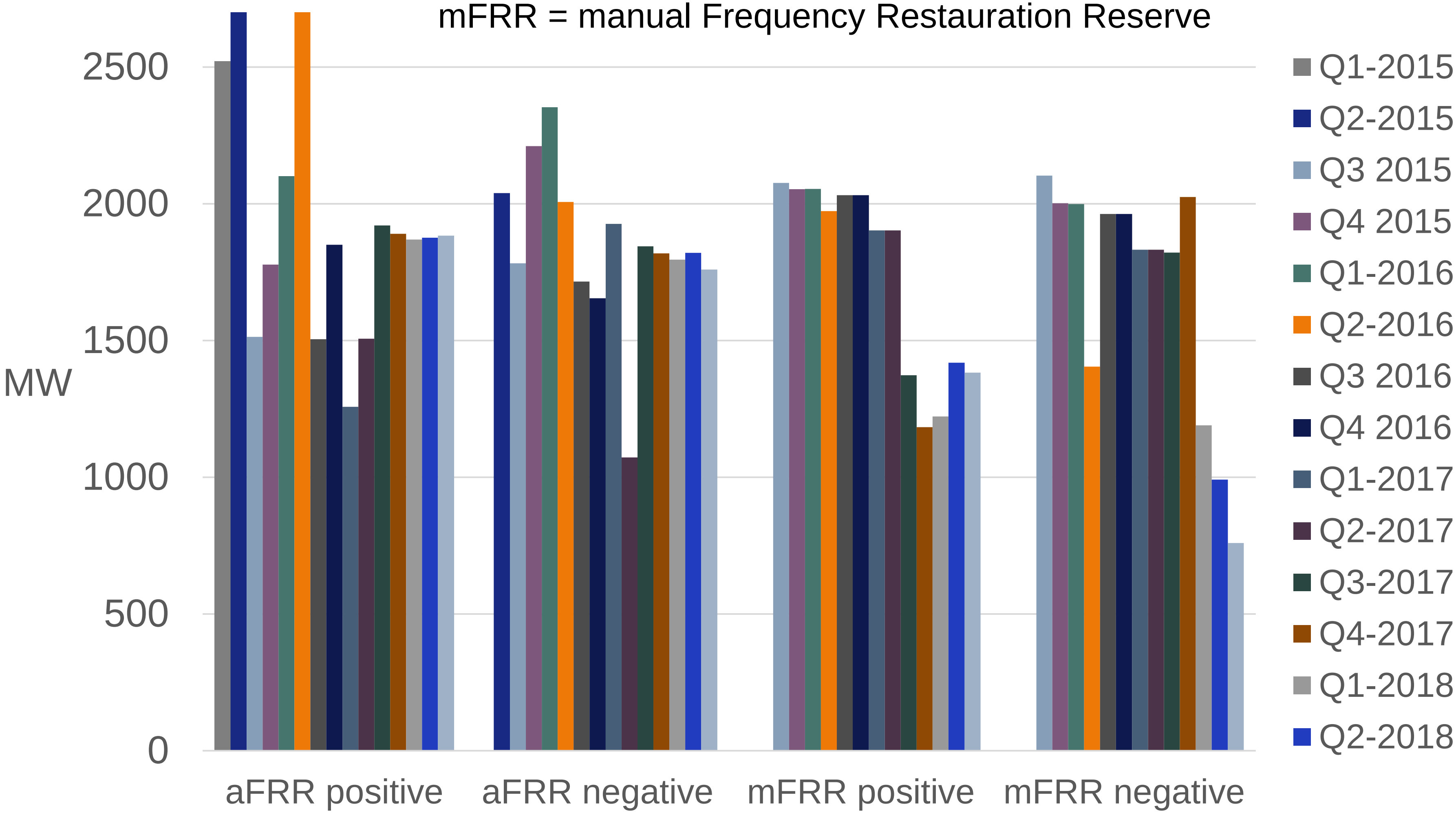
FCR = frequency containment reserve (primary reserve)
aFRR = automatic frequency restoration reserve (secondary reserve)
mFRR = manual frequency restoration reserve (minute reserve)

Source: BNetzA „Monitoringbericht 2020“

Dynamic balancing power tendering tendering in Germany from 2015 - 2018 (aFRR and mFRR)

renac renewables academy

aFRR = automatic Frequency Restauration Reserve
mFRR = manual Frequency Restauration Reserve



https://www.regelleistung.net, 29.8.2018

Methods for dynamic balancing power dimensioning

renac renewables academy

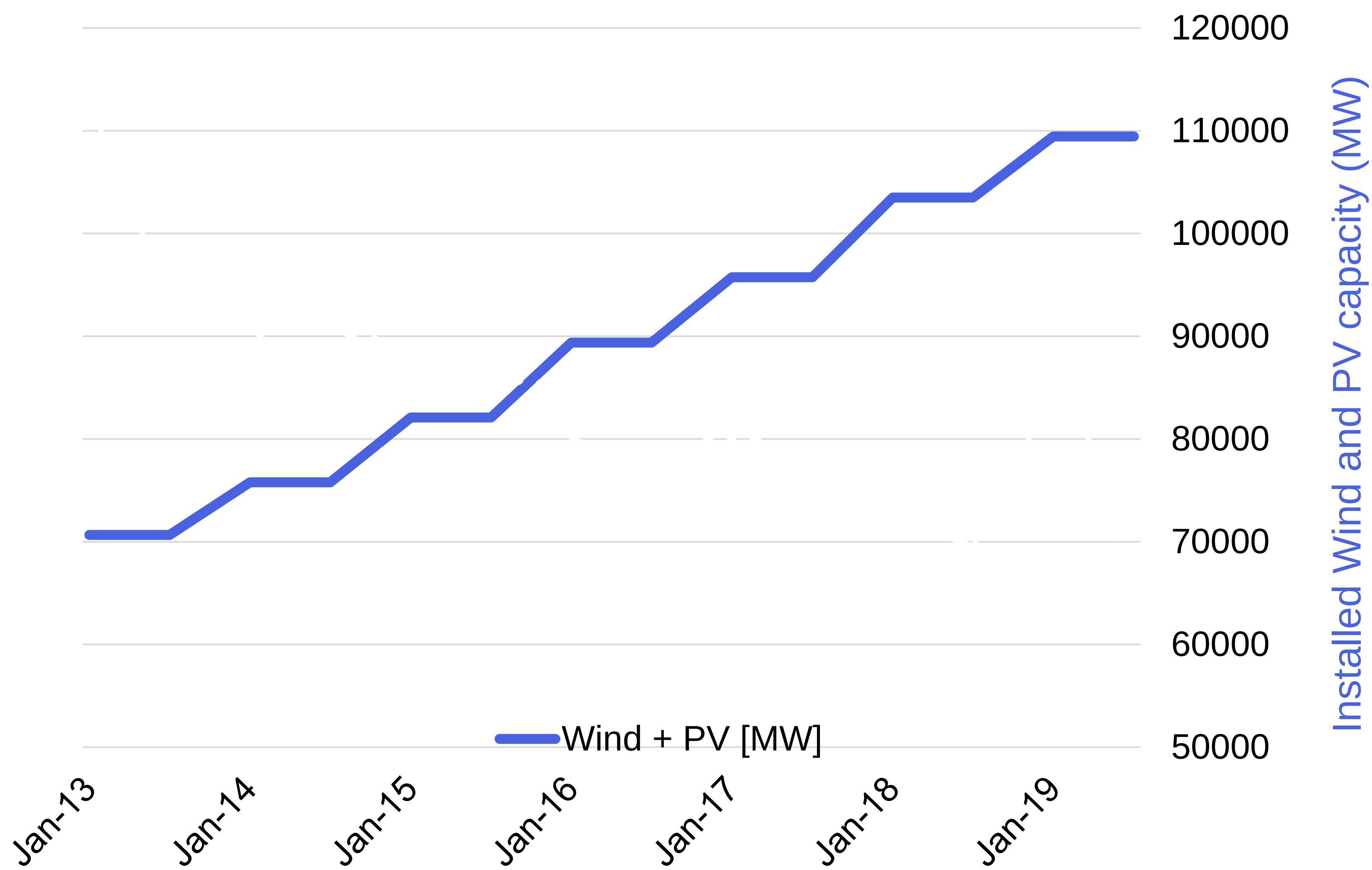
	Method 1	Method 2
Germany	Until 2019	Since 2020
Calculation cycles	Every three months	Weekly (daily possible)
Data	Identical quarters of previous years	Cluster of representative times
Amount of balancing power	Smaller than deterministic methods	Smaller than method 1

Case study result for one year for 4 TSOs in Germany:

Method	Average negative (MW)	Average positive (MW)	Max negative (MW)	Max positive (MW)	Min negative (MW)	Min positive (MW)
1	-2616	3040	-3010	3295	-2120	2518
2	-2472	2819	-3056	3162	-1558	1924

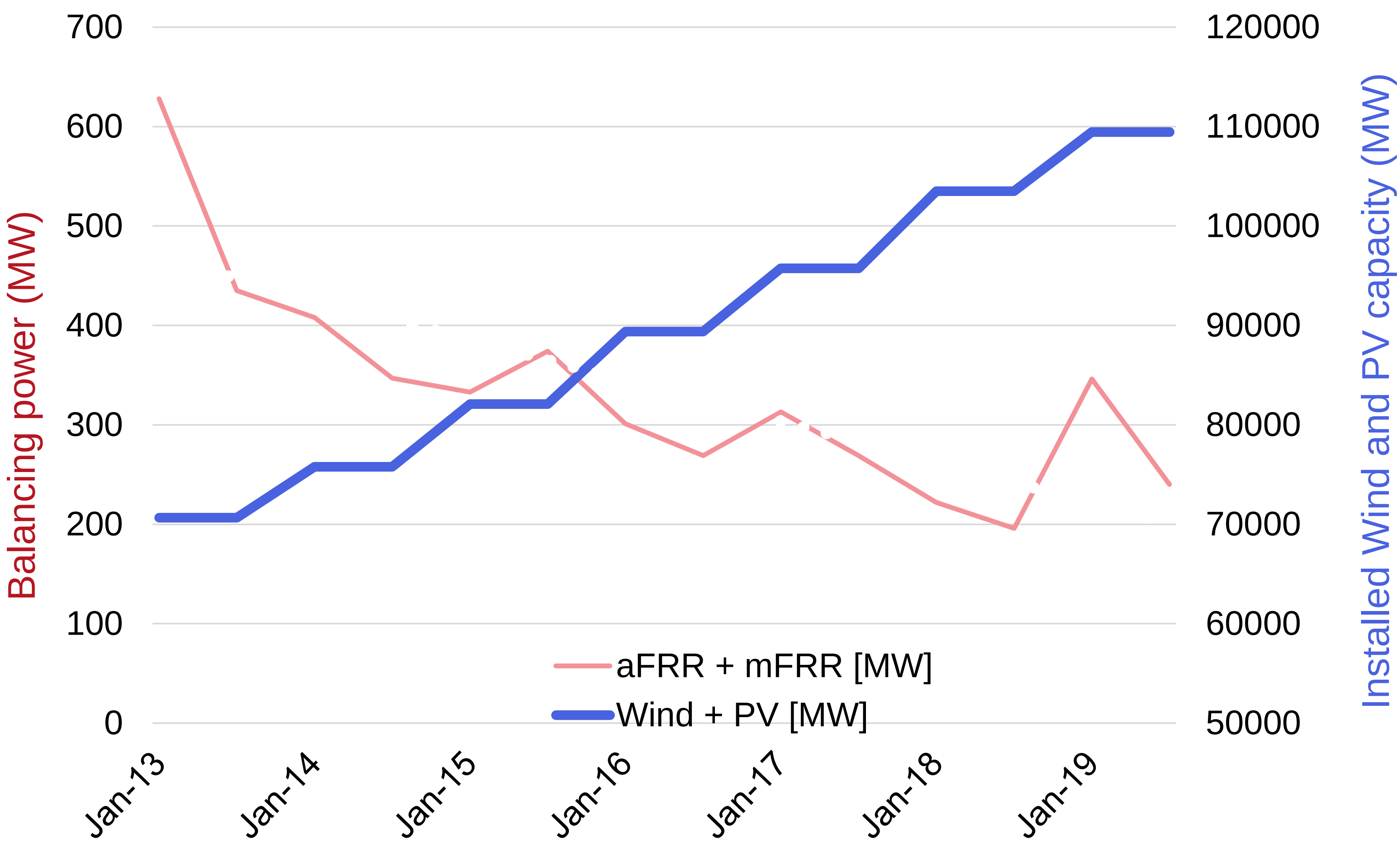
Development of installed wind & PV capacity and used amount of balancing power (aFRR + mFRR) in Germany

renac
renewables academy



Source: BnetzA „Monitoringbericht 2020" and BMWi „Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland"

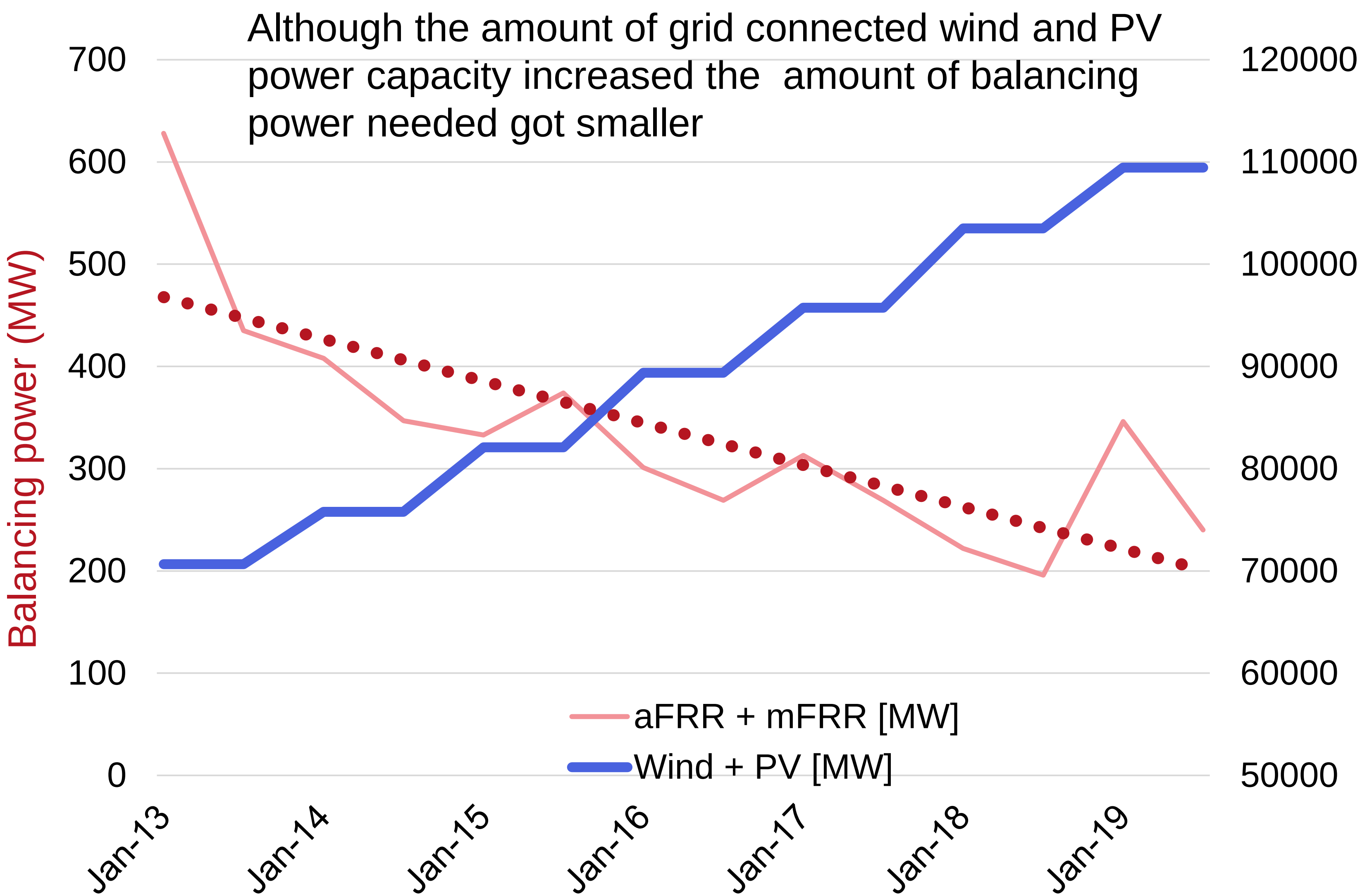
Development of installed wind & PV capacity and used amount of balancing power (aFRR + mFRR) in Germany



Source: BnetzA „Monitoringbericht 2020“ and BMWi „Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland“

Development of installed wind & PV capacity and used amount of balancing power (aFRR + mFRR) in Germany

renac
renewables academy



Source: BnetzA „Monitoringbericht 2020“ and BMWi „Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland“

Thank you!

Albrecht Tiedemann

Renewables Academy (RENAC)

Schönhauser Allee 10-11
D-10119 Berlin
Tel: +49 30 58 708 70 40
Fax: +49 30 58 708 70 88
tiedemann@renac.de

renac
renewables academy

www.renac.de